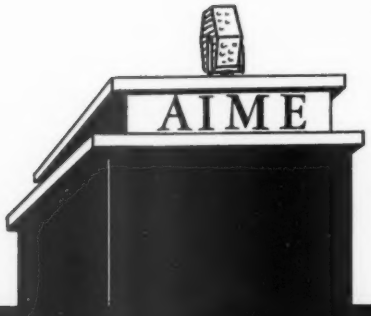
SEPTEMBER 1954 FALL MEETING ISSUE

PETROLEUM BRANCH

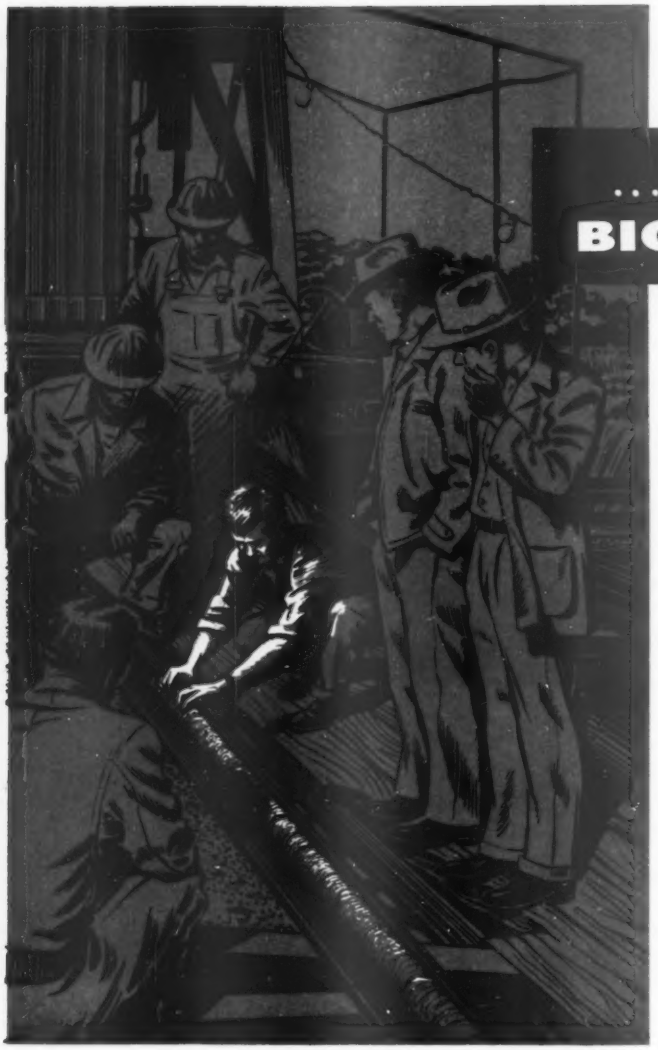
AMERICAN INSTITUTE

OF

MINING AND METALLURGICAL ENGINEERS



JOURNAL OF PETROLEUM TECHNOLOGY



... now comes the BIG QUESTION

You've reached potential pay and cored the section. Now comes the big question — *pay out or play out?* . . . After thousands of dollars and months of effort have been spent to accumulate acreage, drill an exploratory well, and core a probable productive formation, sound business practice demands *good core analyses* . . . and the reliability of these data can be assured by the experience and technical background of the organization performing the work . . . If your best efforts deserve the best possible answer, take advantage of Core Lab's eighteen years' experience in all active areas.

CORE LABORATORIES, INC.

801 CORE STREET, DALLAS, TEXAS

CORE LAB

PETROLEUM RESERVOIR ENGINEERING

DALLAS, HOUSTON, CORPUS CHRISTI, MIDLAND, ABILENE, SAN ANTONIO, TYLER, TULSA, FT. WORTH, WICHITA FALLS, OKLAHOMA CITY, ARDMORE, PAMPA, ARKANSAS CITY, GREAT BEND, NEW ORLEANS, SHREVEPORT, HATTIESBURG, JACKSON, LAFAYETTE, DENVER, BAKERSFIELD, WORLAND, STERLING, BILLINGS, CASPER, EL DORADO, LUBBOCK, FARMINGTON, LOVINGTON; CALGARY, EDMONTON, REGINA, CANADA; VENEZUELA, S. A.

JOURNAL OF PETROLEUM TECHNOLOGY

SEPTEMBER, 1954

OFFICERS • COMMITTEES

Chairman: John R. McMillan
Fullerton Oil Co., Pasadena, Calif.

Vice-Chairmen:

Thomas C. Frick
The Atlantic Refining Co., Dallas, Tex.

D. W. Akins
Ohio Oil Co., Shreveport, La.

EXECUTIVE COMMITTEE:

Burton Atkinson
Pishny & Atkinson, Fort Worth, Tex.

Thomas A. Atkinson
Douglas Oil Co., Paramount, Calif.

Roland Gouldy
Hull-Silk Repressuring Assoc., Wichita Falls, Tex.

Claude R. Hocott
Humble Oil & Refining Co., Houston, Tex.

W. D. Owsley
Halliburton Oil Well Cementing Co., Duncan, Okla.

E. N. Van Duzee
Shell Oil Co., New York, N. Y.

G. L. Yates
Amstutz & Yates, Wichita, Kan.

Charles R. Dodson
National City Bank, New York, N. Y.
Representing M.I.E.D.

Paul R. Schultz
Stanolind Oil & Gas Co., Tulsa, Okla.
Representing M.E.D.

Treasurer: T. A. Pollard
Magnolia Petroleum Co., Dallas, Tex.
Counsel: Robert E. Hardwicke
Hardwicke, Haddaway & Pope, Fort Worth, Tex.
Executive Secretary: Joe B. Alford
AIME, Dallas, Tex.

COMMITTEE CHAIRMEN:

Admissions: F. G. Prutzman
Sun Oil Co., Dallas, Tex.
Advertising: Thomas C. Frick
The Atlantic Refining Co., Dallas, Tex.
Education: Jack Tarner
Phillips Petroleum Co., Bartlesville, Okla.
General Editorial Committee: Glenn M. Stearns
British-American Oil Producing Co., Dallas, Tex.
Membership: Gene L. Scheirman
Shell Oil Co., Kilgore, Tex.
Nominating: Claude R. Hocott
Humble Oil and Refining Co., Houston, Tex.
Transactions Editorial: H. B. Renfro
Petroleum Consultant, Dallas, Tex.
Student Activities: Paul Andrews
Signal Oil & Gas Co., Los Angeles, Calif.
Production Review: R. B. Gilmore, *Chairman*
DeGolyer & MacNaughton, Dallas, Texas
Milton Williams, *Domestic*
Humble Oil & Refining Co., Houston, Tex.
A. H. Chapman, *Foreign*
Arabian-American Oil Co., Washington, D. C.
Technology: William L. Horner, *Chairman*
Core Laboratories, Inc., Dallas, Texas
Preston E. Chaney, *Drilling*
Sun Oil Co., Beaumont, Tex.
W. W. Hammond, *Geological Engineering*
Ralph E. Fair, Inc., San Antonio, Tex.
William H. Speaker, *Natural Gas Engineering*
Magnolia Petroleum Co., Dallas, Texas
John H. Thacher, *Petroleum Economics*
California Research Corp., San Francisco, Calif.
Lewis Finch, Jr., *Production Engineering*
Stanolind Oil & Gas Co., Tulsa, Okla.
L. P. Wharton, *Reservoir Engineering*
The Atlantic Refining Co., Dallas, Tex.

OFFICERS OF THE AIME:

President: Leo F. Reinartz
Vice-Presidents: O. B. J. Fraser, J. B. Morrow, Lloyd E. Elkins, A. B. Kinzel, T. B. Counselman, and Harold Decker
President-Elect: H. DeWitt Smith
Past President: Andrew Fletcher
Treasurer and Controller: Gail F. Moulton
Secretary: E. H. Robie

CONTENTS

A COMMENT ON PRESENT TREND IN ENGINEERING EDUCATION
by Charles R. Dodson 9

A CORRELATING DEVICE FOR PREDICTING RESERVOIR PERFORMANCE
by Geo. J. Heuer, Jr., and Harry H. Power 10

A NEW METHOD FOR CONTROL OF INCOMPETENT SAND FORMATIONS
by H. B. Ritch 15

REPORT AND INTERPRETATION
by Virginia Beilharz 19

PETROLEUM BRANCH FALL MEETING SECTION 29

PACIFIC PETROLEUM CHAPTER FALL MEETING 42

TECHNICAL BULLETIN SECTION 47

COMPARISON OF METHODS FOR ANALYZING A WATER DRIVE FIELD, TORCHLIGHT TENSLEEP RESERVOIR, WYOMING
by F. M. Stewart, F. H. Gallaway, and R. E. Gladfelter 105

A MAGNETIC SUSCEPTIBILITY METHOD FOR THE DETERMINATION OF LIQUID SATURATION IN POROUS MATERIALS
By J. W. Whalen 111

USE OF RADIOACTIVE IODINE AS A TRACER IN WATER-FLOODING OPERATIONS
by J. Wade Watkins and E. S. Mardock 117

SOLUTION OF THE EQUATIONS OF UNSTEADY-STATE TWO-PHASE FLOW IN OIL RESERVOIRS
by W. J. West, W. W. Garvin, and J. W. Sheldon . . . 125

STUDY OF UNDERSATURATION DURING REPRESSURING AND SUPERSATURATION DURING FLOW OF OIL TO WELLS
by Ralph V. Higgins 127

GAS HYDRATES OF HYDROGEN SULFIDE METHANE MIXTURES
by Leslie J. Noaker and Donald L. Katz 135

MEET THE AUTHORS 138

PETROLEUM BRANCH, AIME STUDENT ACTIVITIES 141

PERSONALS 149

ADVERTISERS' INDEX 152

EDITORS • STAFF

Advisory Editor: Glenn M. Stearns

Editorial Director: Joe B. Alford

Editor: R. W. Taylor

Production Manager: Jan Gartman

Editorial Assistants: Virginia Beilharz, Hattie Hight, Jo Themar

Advertising Director: Richard C. Wipperman

Journal of Petroleum Technology is published monthly by the Petroleum Branch, American Institute of Mining and Metallurgical Engineers, Inc., at 800 Fidelity Union Bldg., Dallas 1, Tex. Entered as second class matter at the Post Office at Dallas, Tex. Domestic Subscription: North, South, and Central America, $8; foreign, $10; to AIME members, $6 (or $4 if in combination with subscription to either Journal of Metals or Mining Engineering). Single copies, 75 cents in U. S. A., $1, foreign; special issues, $1.50. Registered cable address, AIME. Printed in U. S. A. Views expressed herein are not necessarily those of the AIME.

THE AIME ALSO PUBLISHES MINING ENGINEERING AND JOURNAL OF METALS

COPYRIGHT 1954 — AMERICAN INSTITUTE OF MINING & METALLURGICAL ENGINEERS, INC.

The BAKER
RETAINER PRODUCTION PACKER...

What is a Permanent-Type Well Completion?

HERE ARE THE FACTS:

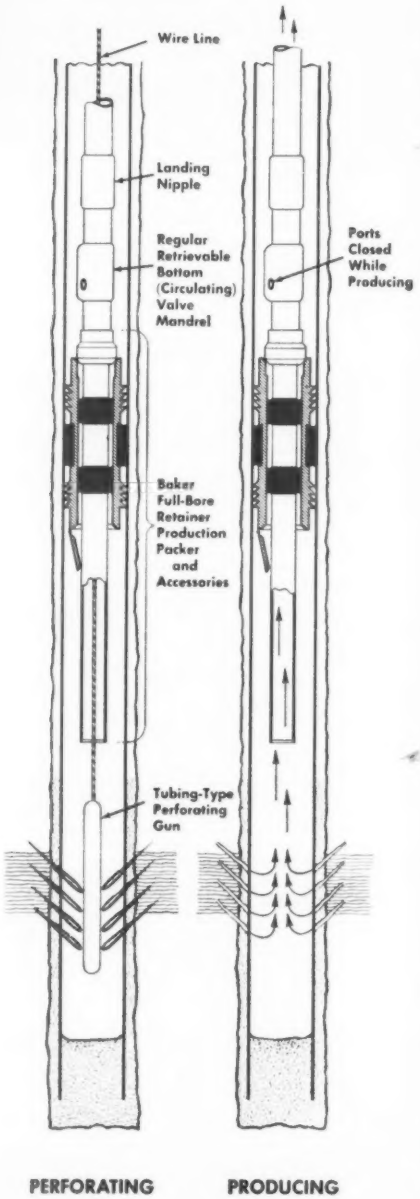
A Permanent-Type Well Completion is generally considered to be an installation providing for completion, production, repair or recompletion in other zones without requiring a drilling or work-over rig.

All tools are run *through the tubing string* after it is landed and nippled up.

If the completion is successful, the tubing need never again be moved until all zones of the selected interval have been exhausted.

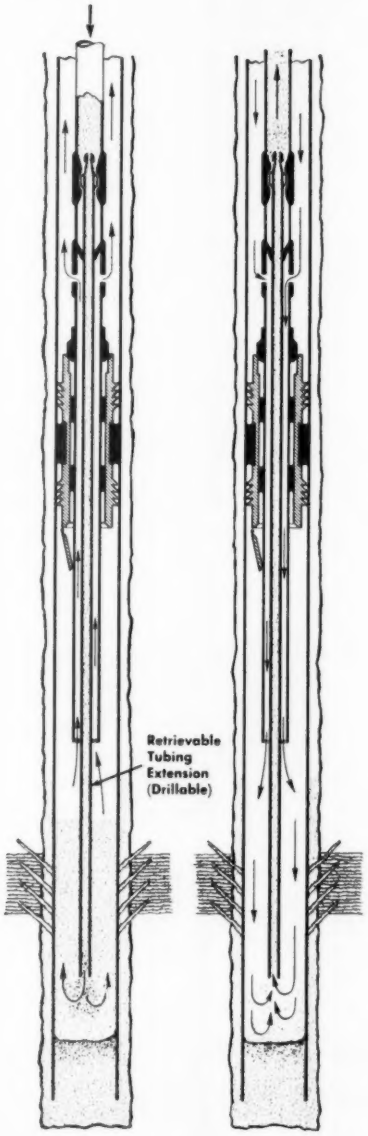
Advantages Claimed for Permanent-Type Well Completions

1. **SAVES AT LEAST ONE TO TWO DAYS RIG TIME during the original completion.**
2. **ELIMINATES COST OF SEPARATE TESTING AND SQUEEZE TOOLS.**
3. **REDUCES WORK-OVER COST AS MUCH AS 75%, by eliminating work-over rig, cost of mud, time and equipment to kill well. Reduces loss of production through saving in work-over time.**
4. **PERMITS THE ECONOMICAL TESTING OF THIN OR QUESTIONABLE SECTIONS.**
5. **PERMITS USE OF WATER INSTEAD OF MUD while perforating completing, or re-completing. This practice reduces formation contamination and may result in an increase in the productivity of the zone.**
6. **PERMITS A MORE ACCURATE ANALYSIS OF RESERVOIR POTENTIAL.**
7. **KEEPS WELL UNDER CONTROL AT ALL TIMES.**



Where PACKERS are required... specify a...

for Permanent-Type Well Completions

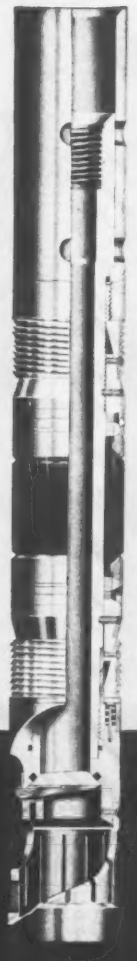


SQUEEZING REVERSING

BAKER PACKERS ADD PERMANENCE TO PERMANENT-TYPE WELL COMPLETIONS

When you select a Packer for a Permanent-Type Well Completion, remember this fact: of all the tools used in permanent-type well completions, only the *Packer* is required to be *permanent.* Guns, Extensions, Plugs, Gas-Lift and Circulating Valves can be removed or replaced on wire line . . : but the Packer, like the casing, is required to perform for the life of the selected producing intervals.

Baker Packer Completions are Permanent Completions from the standpoint of packer performance. Check these important advantages of the Baker Packer in Permanent-Type Well Completions:



Advantages of Baker Retainer Production Packer in Permanent-Type Well Completions:

1. **PERMANENT, RELIABLE PACK-OFF will hold against any pressure differential from above or below that is safe for the casing.**
2. **FREE TUBING STRING . . . neither set-down tubing weight nor tubing tension required to achieve and maintain pack-off. Tubing can be anchored to Packer if desired.**
3. **CAN BE USED AS A SQUEEZE OR A PRODUCTION TOOL.**
4. **MEETS PERMANENT-TYPE WELL COMPLETION DIMENSIONAL REQUIREMENTS.**
5. **CAN BE SET ON WIRE LINE.**
6. **PERMITS EASY REMOVAL OF TUBING STRING.**
7. **READILY DRILLABLE IN CASE OF EMERGENCY OR NEED.**

BAKER OIL TOOLS, INC.
HOUSTON • LOS ANGELES • NEW YORK

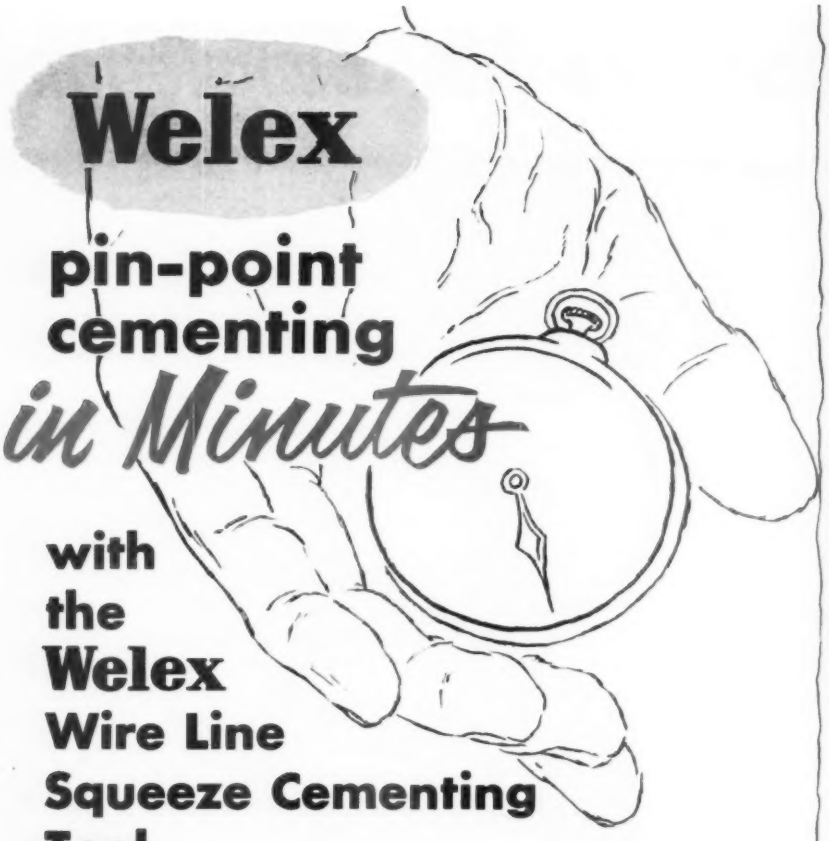
BAKER

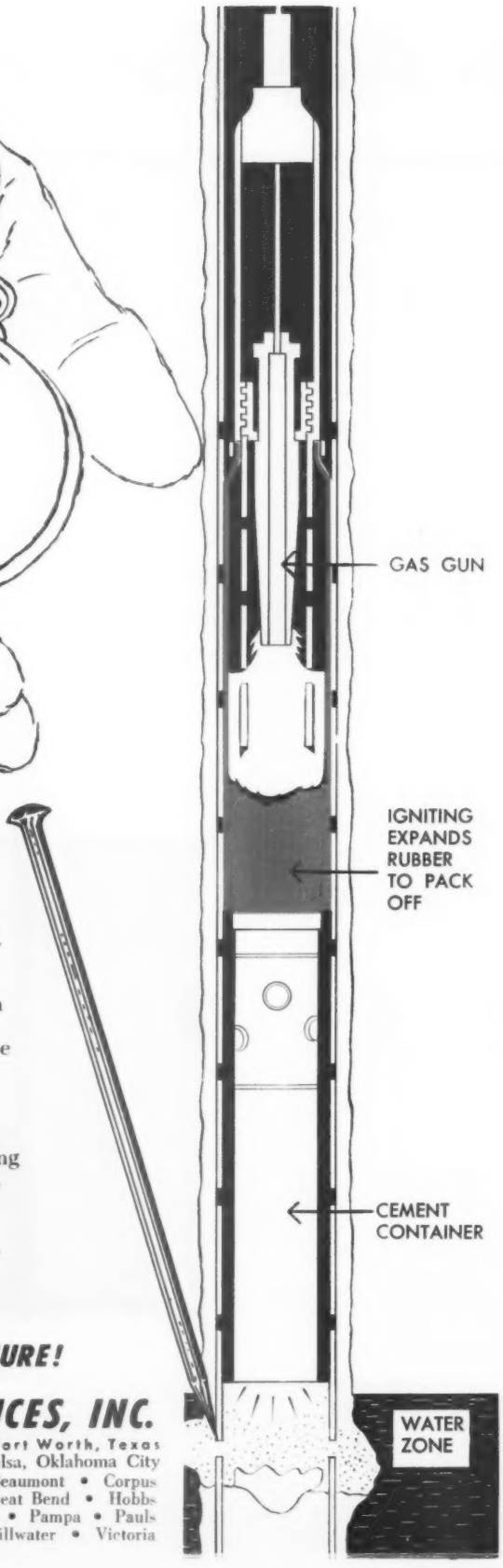
RETAINER PRODUCTION PACKER
PRODUCT NO. 415-D

Welex

pin-point cementing *in Minutes*

with the Welex Wire Line Squeeze Cementing Tool





For water problems . . . bottom hole water, communication between zones, water infiltration of the perforations, leaky shoes, or leaky casing, the Welex Squeeze Cementer offers the maximum in efficient shutoff.

The only cement squeeze tool which can be run on a wire line, the cement is forced into place by the firing of a high pressure gas gun which expands packer against the casing as a packoff and squeezes the cement into place under higher pressure than any surface cement pump.

The packer cannot stick. It instantly releases when the cement is ejected from the tool. Plugback depth can be controlled from a minimum of one foot. Stage cementing permits economical plugbacks up to approximately 50 feet.

You save money with the Welex Squeeze Cementer by eliminating round tripping of tubing, pump truck service, cement retainers, and by using a minimum of cement. You save by getting back in production faster.

Call Welex and be SURE!

Welex JET SERVICES, INC.

General Offices: 1400 East Berry, Fort Worth, Texas
Division Offices: Houston, Midland, Tulsa, Oklahoma City
District Offices: Abilene • Ardmore • Beaumont • Corpus Christi • Falfurrias • Gainesville • Great Bend • Hobbs Houston • Lafayette • Liberal • Odessa • Pampa • Pauls Valley • San Angelo • Shawnee • Stillwater • Victoria Wichita Falls

It Pays . . .

. . . to put the shots where they count!

McCULLOUGH M-3 BULLET GUN
and **GLASS JET *PERFORATORS***

Simultaneous firing (holes in the casing exactly as in the gun itself), exact measurements, multiple zone shooting, burrless bullets, and up to 50% deeper penetration. Write for your copy of "HOW TO GET MORE OIL."

McCullough
TOOL COMPANY
LOS ANGELES • HOUSTON • EDMONTON
OVER 40 OIL FIELD SERVICE BRANCHES
SERVICE ANYWHERE—ANYTIME

FOR BEST RESULTS LOG AND PERFORATE BY McCULLOUGH

PROBLEM WELL MADE PROFITABLE WITH

ELECTRIC PILOT

Oil increased 80%, water eliminated after Dowell Selective Acidizing, Permeability & Water Location Surveys

A well completed in a limestone formation was pumping 61 barrels of oil and 85 barrels of water per day. The operator called Dowell to help him with the workover.

Dowell engineers used Electric Pilot services to help bring the well's production to a profitable 109 barrels of pipeline oil per day flowing. Here's the way the job went.

A water location survey showed that the water was entering the hole at the bottom of the upper set of perforations. A relative permeability survey using the spinner, indicated that approximately 86% of the permeability was in the upper set of perforations with over 50% at the point of water entry.

Then, as a final step, the lower perforated zone was acidized selectively with the pilot. A packer isolated the water zone during and after the treatment. The resulting 109 BOPD, flowing, was recorded with the well "pinched in" and *after* a period of flush production.

Other wire-line services performed with the Electric Pilot include Glass Gun perforating; caliper, temperature and channel determination surveys; and Gamma Ray Logging. For complete information on the Electric Pilot and the many other Dowell services—including fracturing and acidizing—contact your nearby Dowell office. Or write to DOWELL INCORPORATED, Tulsa 1, Oklahoma, Dept. I-15.

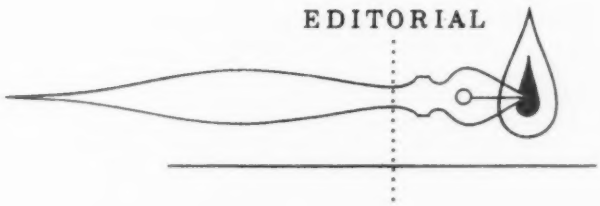
DOWELL SERVICE

chemical services for the oil industry

DOWELL

A SERVICE SUBSIDIARY OF THE DOW CHEMICAL COMPANY

EDITORIAL



A COMMENT on PRESENT TRENDS in ENGINEERING EDUCATION

CHARLES R. DODSON

BRANCH EXECUTIVE COMMITTEE MEMBER
REPRESENTING MINERAL INDUSTRIES EDUCATION COMMITTEE

Today, any discussion of engineering education is underlined by the financial condition of the schools, increased emphasis on research, and low salaries paid to professors. This is a cause of concern to most engineers since they maintain a deep interest and desire to see engineering education improved and kept abreast of technological progress. This interest appears to increase with time and in proportion to the engineer's advancement in industry, and is particularly true of men who visit the engineering schools on recruiting programs for their companies.

Engineering educators, professional societies and accreditation groups are constantly working to improve engineering education. Many schools have committees composed of prominent men in industry that consult and advise on matters of curriculum and course content. As a result of this interest and cooperation, there has been an increasing emphasis on fundamental engineering courses and less specialization in the normal four-year undergraduate engineering curricula.

The matter of courses for engineering students is not the issue today that it was a number of years ago. Basic courses compose from 75 to 85 per cent of current engineering curricula. In professional curricula, petroleum engineering for example, the rest of the curricula is assigned to geology and courses dealing with flow properties of hydrocarbons, and the like. It can be said that currently the four-year curricula suits most engineers and the requirements of industry.

Most interested parties approve this trend of increased emphasis on fundamental engineering courses, but there is one feature in the present trend that bears watching, namely, the possibility of over-emphasis on graduate study and research.

A recent report by an industry committee submitted to one of the country's largest universities made a recommendation to the effect that no instructors be hired in the future unless they had a PhD degree and were interested in undertaking research work. A similar qualification for instructors has been noted in the help-wanted columns and in requests for assistance in finding instructors.

The basic intent in the PhD requirement is to improve the quality of the engineering faculty and, in regard to research, most universities feel that it is essential to their well-being. Not only does it bring in additional income in the form of grants and fees, but also many faculty men remain on the teaching staff because there is opportunity to do research and obtain publication credit. Also, the faculty promotions in rank, salary increases and opportunities in industry generally come to those having a good publication record.

As a consequence of the above, it is pertinent to raise a question as to what is the effect of the present trend on the normal four-year undergraduate program and its objectives.

Competent instruction is the backbone of engineering education. However, a faculty composed of men primarily interested in graduate study and research must have relatively light teaching duties and this generally makes them unavailable for the basic engineering courses, which are difficult to teach and require a large amount of time for course preparation, student consultation, and testing.

From the school's point of view, this situation presents many difficulties. It is important that they maintain graduate study and research activities in order to achieve growth and academic advancement. They recognize that it is expensive and requires a larger staff than would otherwise be needed for the undergraduate curricula.

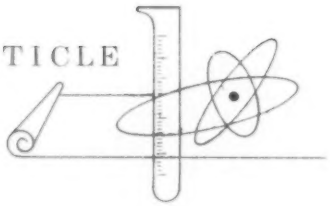
There is no doubt that each school desires to have its best men teaching the basic courses. Consequently, alumni and industry can be of material assistance by letting the engineering schools know that their problems are understood and that industry will support them in maintaining the best possible undergraduate instruction.

Much can be done by the schools themselves by consolidating curricula, eliminating most special courses and thereby reducing the number of instructors on the staff. This would allow them to retain their most capable men and, on present budgets, pay substantially higher salaries.

It is the writer's opinion that the present emphasis on graduate study and research will have detrimental effects on the undergraduate program and that industry should work with the schools and assure them as to the importance of maintaining the highest possible standards of instruction. This should take precedence over graduate study and research if there is any conflict.

★★★

FEATURE ARTICLE



A CORRELATING DEVICE for PREDICTING RESERVOIR PERFORMANCE

GEORGE J. HEUER, JR.
STUDENT ASSOCIATE, AIME

HARRY H. POWER*
MEMBER AIME

TEXAS PETROLEUM RESEARCH COMMITTEE
UNIVERSITY OF TEXAS DIVISION
UNIVERSITY OF TEXAS
AUSTIN, TEXAS

Abstract

This paper develops a means for predicting the relative permeability of gas to oil for a reservoir on the basis of early production data. The method is based on the observation that a log-log plot of the cumulative gas versus the cumulative oil production frequently results in a straight line, particularly in the case of solution-gas drive reservoirs, or reservoirs with a partial or delayed water drive.

The method of calculating the relative permeability of gas to oil from this relationship is discussed, together with the specific application to the actual behavior of the Schuler Jones sand pool, Union County, Ark.

Introduction

Ultimately, the determination of accurate relative permeability values may be solved, partially or completely, in the laboratory. At present the difficulty in obtaining representative core samples, the proper weighting of relative permeability values and the inadequacies existing in reservoir equations make it desirable to find some way for the determination of the ratio k_g/k_o which, when substituted in existing equations, will permit the prediction of future reservoir performance.

The experimental values of relative permeability as determined in the laboratory do not coincide closely with values calculated from field production data. This difference, probably, is a reflection of the original fluid distribution as well as that resulting from dynamic conditions of flow, which result in non-uniform saturation-permeability relationships from one portion of the reservoir to another. The calculated relative permeability for the field is a weighted average value, representing all the instantaneous variations in permeability along flow lines into the well-bore due to differences in absolute permeability, saturation, pressure and pressure gradient.

At present, it is virtually impossible to simulate these conditions in the laboratory. This paper was written in an attempt to determine the relative permeability of the gas to oil phases from the relationship between oil and gas cumulative production. A prior method for determining field relative permeability by means of the "conformance factor" has been described by Patton.[1]

The Cumulative Gas-Oil Relationship

The log-log plot of cumulative gas versus oil production has been known and used as a correlating device since 1935.[2] Preliminary investigations were made by plotting the production data from numerous fields selected at random. A straight line relationship (Fig. 1) resulted in a majority of the cases. In those instances where deviation from the straight line relationship existed, a tentative reason was assigned for the departure, such as the appearance of an active water drive.

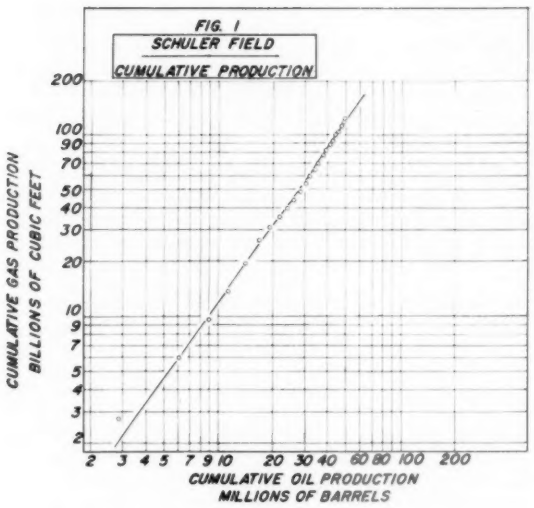
Obviously, systematic deviation (upward curvature) of the line is a reflection of an increase in the rate of gas production, while downward deviation shows a decreasing rate. Fig. 1 for the Schuler Jones sand pool shows the straight line relationship which is characteristic of the majority of fields under gas drive (or partial water drive) which have been studied. The West Edmond Hunton field[3] illustrates upward curvature, while the Oklahoma City field[4] shows a downward deviation. In the latter case the low gas-oil ratio undoubtedly reflects the strong gravity drainage known to be operative.

Space prohibits the inclusion of more graphs showing the cumulative oil to gas relationship, but on the basis

*Professor, Department of Petroleum Engineering, University of Texas.

[1]References given at end of paper.

Paper received in Petroleum Branch office on July 15, 1954.



of plots made for some 50 fields, the following tentative observations are made:

1. The straight line relationship exists for at least 80 per cent of the solution-gas drive fields studied;

2. Partial or complete water drive or gravity drainage causes the straight-line relationship to deviate in about 50 per cent of the cases;

3. Gas injection may or may not cause systematic deviation; the departure from a straight line relationship is probably related to and a measure of an increasing permeability to gas;

4. Water injection, generally, causes downward deviation, except where coincident gas injection offsets this tendency;

5. Where a gas cap exists and the pressure is above saturation pressure, the graph for a water-drive field often plots as a straight line;

6. The log-log plots for condensate fields, gas fields and oil fields having high gas-oil ratios apparently show the linear relationship more consistently than do the plots for other types of fields.

Before detailed analyses of reservoir performance are possible, it will be necessary to study the data from many more fields and classify them on the basis of such factors as fluids present, drive mechanisms, formation characteristics, porosity and permeability variations and the application of extraneous fluid injection.

Where the linear relationship exists, the equations relating cumulative oil production, $\overline{Q}_o$, with cumulative gas production, $\overline{Q}_g$, are calculated by the method of least squares. The equations take the form

$$\overline{Q}_g = a\,(\overline{Q}_o)^b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where, a is the intercept of the cumulative gas versus oil plot and b is the slope of the cumulative gas versus oil plot.

No definite limits are found for the constant a, while the exponent b ranges from 0.5 to 2.0. In fitting the equations to actual data, an accuracy within 10 per cent has been obtained by using the production data for the first three years. The relationship depends to some extent upon the intensity of field development. The use of early production data based on one or two wells only often leads to indeterminate results.

A comparison of the cumulative production of the Schuler Jones sand pool predicted by means of Equation (1) with the actual production data reflects a maximum error of 9 per cent and an average error of 2.5 per cent over a period of 12 years.

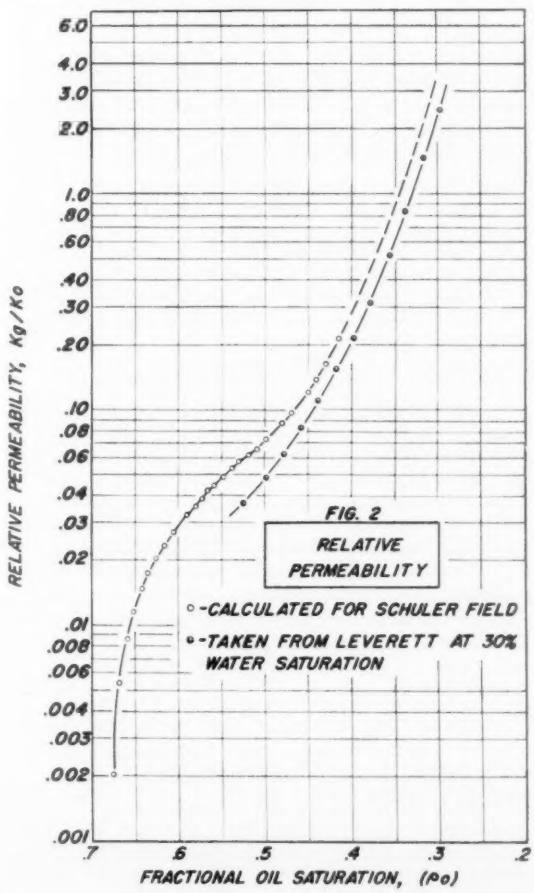
Before Equation (1) was applied specifically to the Schuler field, however, an investigation was made to determine whether the relative permeability curves resulting from laboratory investigations and published by different investigators would produce the straight line cumulative plot discovered by observation. The lower curve of Fig. 2 shows an interpolation of Leverett's relative permeability curves[5] for a connate water saturation of 30 per cent. A recent communication* reports an average connate water saturation for the Schuler field of 30.2 per cent.

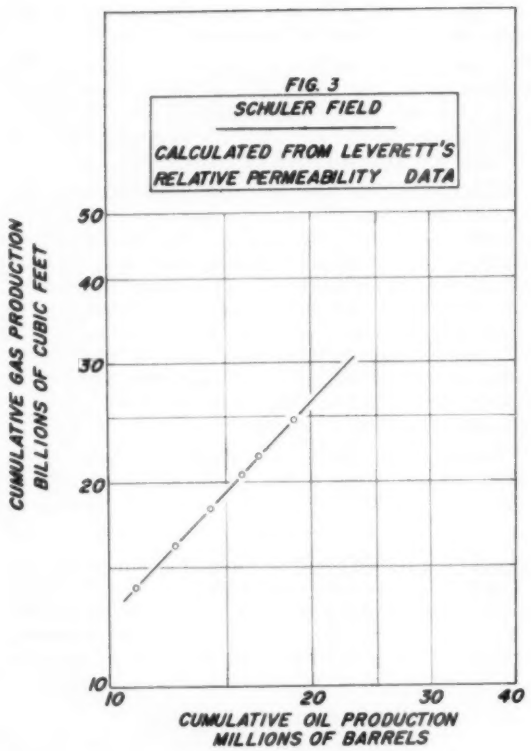
Values of the gas to oil permeability ratio, k_g/k_o, taken from Leverett's data, were substituted in the equation

$$R = (k_g/k_o)\,\alpha + S \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where, R is the instantaneous gas-oil ratio, S is the gas saturation at reservoir conditions, and α is a dimensionless factor defined by Muskat.[6] Data for the Schuler field were used for the determination of the solubility, S, and the reservoir volume factor β_o. Fig. 3, based on

*Arkansas Oil and Gas Commission





Leverett's permeability data, was developed by arbitrarily selecting a series of values for cumulative oil production and corresponding values for cumulative gas production. The fractional oil saturation, ρ_o, was found from these values by solving the equation

$$\overline{Q}_o = 7{,}758.4(A)(f)\left(\frac{\rho_{oi}}{\beta_{oi}} - \frac{\rho_o}{\beta_o}\right) \quad . \quad . \quad . \quad (3)$$

where, A is the area of the field, acres; β_o is the volume factor of the reservoir oil (β_{oi} the initial value); ρ_o is the fractional residual oil (ρ_{oi} the initial value); and f is the fractional porosity and Q_o is the cumulative stock tank oil per acre foot.

For the Schuler pool, Equation (3) reduces to

$$\overline{Q}_o = 98{,}132{,}000 - 203{,}858{,}000\ (\rho_o/\beta_o)^* \quad . \quad . \quad . \quad (4)$$

After the fractional oil saturation, ρ_o was calculated by means of Equation (4), a corresponding value for k_g/k_o was read from Fig. 2 and the gas-oil ratio determined for a small pressure decrement. The actual oil production over this interval multiplied by the gas-oil ratio resulted in a corresponding quantity for the gas production. These two amounts, added to the preceding and respective cumulative figures, gave the new values for cumulative oil and gas production.

The range of Fig. 3 is rather limited, since Leverett's data do not show the small values of relative permeability existing during the early productive history. Fig. 2 also shows the good correlation between Leverett's curve and the one calculated for the Schuler Jones sand pool based on Equation (1).

*The determination of the constants in Equation (4) depends necessarily on the existing estimates of the original oil in place. See Reference (13).

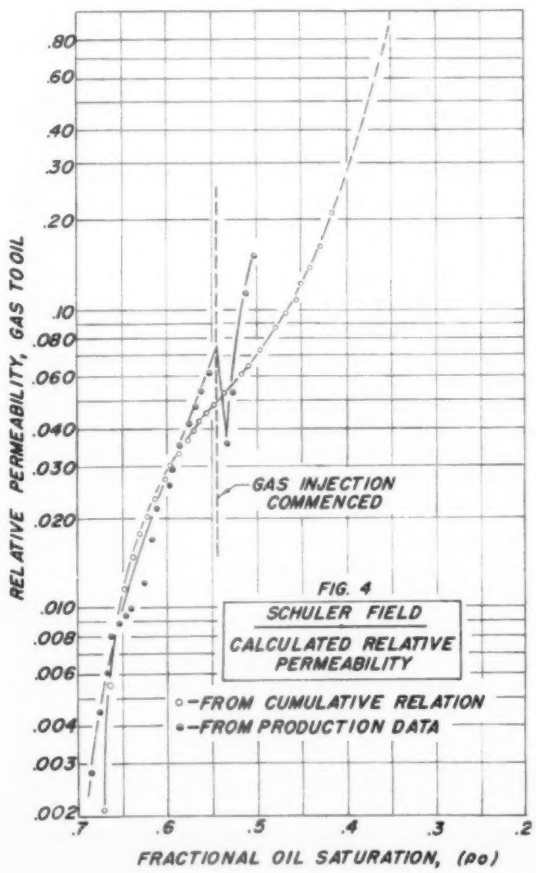
Application to the Schuler Jones Sand Pool

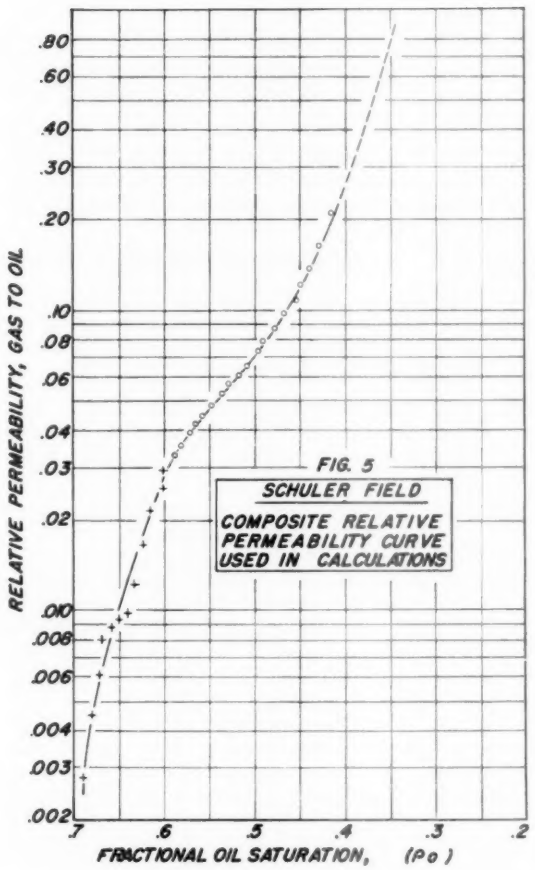
The Schuler Jones sand pool has been described in several publications.[6, 7, 8, 9, 12] The most recent estimate of original oil in place is 98,132,000 bbls, based on a productive area of 4,216 acres and a productive oil zone of 130,078 acre-ft.[12]

Muskat's differential equation for solution gas drive was used to predict the performance of the Schuler Jones sand pool after the inclusion of the proper k_g/k_o values as determined from the relationship shown in Fig. 1. This equation is

$$\frac{d\rho_o}{dp} = \frac{\rho_o\lambda(p) + (1 - \rho_o - \rho_w)\,\xi(p) + \rho_o\eta(p)\psi}{1 + (\mu_o/\mu_g)\psi} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

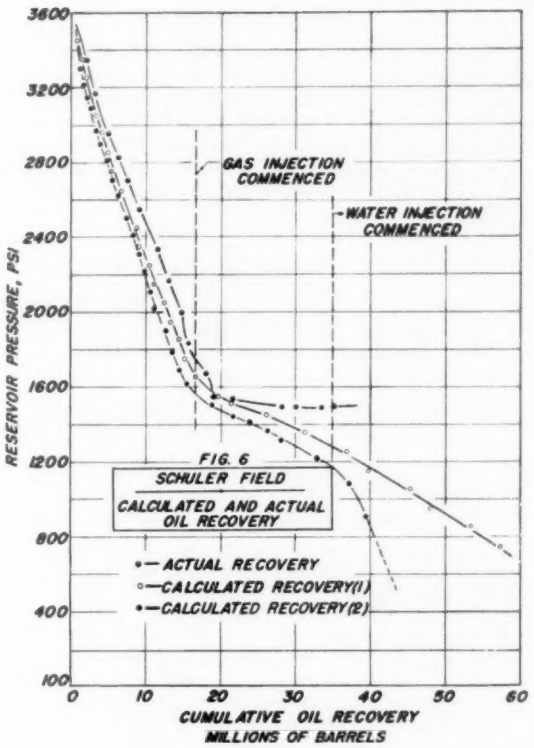
Equation (5) and modifications thereof to include the return of produced gas to the reservoir have been described previously.[6] A numerical integration of the equation was used in order to increase the accuracy of the results. The first four values were obtained by the Runge-Kutta method and the remaining values by the Milne method. The values for the ratio, k_g/k_o were calculated in the following manner. After the determination of a fractional oil saturation for the pressure decrement chosen, the corresponding value for $\overline{Q}_o$ was found from Equation (4). This value, substituted in Equation (1) permitted the calculation of $\overline{Q}_g$. The values for Q_o and Q_g were determined by subtracting the values of $\overline{Q}_o$ and $\overline{Q}_g$ at the beginning of the decre-





ment from those obtained at the end of the decrement. These, in turn, when substituted in Equation (2), permitted the calculation of the ratio k_g/k_o for the decrement. Values of k_g/k_o, as determined, were plotted against corresponding values of ρ_o, as shown in Fig. 2. The integration of Equation (5) was carried out to a minimum or limiting pressure of 100 lbs/sq in. on the assumption that the field performance would be closely related to that associated with solution gas-drive.

The calculated values of k_g/k_o were compared to those determined from actual production data as shown in Fig. 4. A composite curve, Fig. 5 was drawn using the values of k_g/k_o found from actual production data for the first three years and the values calculated from the cumulative gas-oil curve thereafter. The extrapolation of the calculated k_g/k_o curve was done logarithmically from Fig. 4. The results were plotted in Fig. 2, which gave a good correlation with Leverett's curve. After the final k_g/k_o curve was developed, the integration of the modified Equation (5) was repeated, making allowance for the actual return of 90 per cent of the produced gas initiated at a reservoir pressure of 1,542 lbs/sq in. The final results are shown in Fig. 6, where values of the fractional oil saturation, ρ_o, have been converted to cumulative stock tank oil production, $\overline{Q}_o$ by means of Equation (4). Gas-oil ratios were calculated by means of Equation (2) and from data selected from the final k_g/k_o curve (Fig. 5). Referring to Fig. 6, the curve labeled "Calculated Recovery (1)" is based on an original oil in place value of 113,132 million bbls, while the curve labeled "Calculated Recovery (2)" is based on an estimated original oil in place of 98,132,000 bbls.



Up to the time of water injection, the maximum error between the calculated pressure and the actual pressure for a given cumulative oil production was approximately 13 per cent, while the average error was much less. Moreover, water production became a factor sometime before the initiation of water injection, indicating the probability that the solution-gas mechanism was supplemented by other sources of reservoir energy.

Conclusions

For the most part, the cumulative gas versus oil plot on log-log paper is a straight line for the solution-gas drive fields examined. For those cases where deviation exists, the performance may be attributed to the influence of a gas cap, or to a partial water drive, gravity drainage, or water injection. The amount of actual field data necessary to extrapolate the cumulative oil-gas relationship with confidence undoubtedly varies and should depend to a large extent upon the reservoir factors known to be operative. A history of three years was considered to be sufficient to make a reliable extrapolation of the Schuler Jones sand pool which was found later to be related to but not actually under solution gas drive. For other reservoirs, less data permitted reliable extrapolation for engineering purposes. For those cases where the producing mechanism is at wide variance with solution gas drive performance, the straight line log-log plot should probably be replaced by a more involved empirical solution of the future functional relationship. These problems are matters for future analysis.

Acknowledgment

The authors wish to acknowledge the assistance of the Texas Railroad Commission, the Arkansas Oil and Gas Commission, and the Lion Oil Co. Comments made by Morris Muskat were helpful. Special acknowledgment is made to the Texas Petroleum Research Committee which provided funds for this investigation and to G. H. Fancher, director, for his encouragement in pursuing the project.

References

1. Patton, E. C., Jr.: "Evaluation of Pressure Maintenance by Internal Gas Injection in Volumetrically Controlled Reservoirs," *Trans.* AIME (1947) **170**, 112.
2. Power, H. H.: "Sub-Surface Conditions in the Crescent Field," Company Report, October, 1935.
3. Littlefield, M., Gray L. L., and Godbold, A. C.: "Reservoir Study of the West Edmond Hunton Pool, Oklahoma," *Trans.* AIME (1942) **174**, 131.
4. Katz, D. L.: "Possibilities of Secondary Recovery for the Oklahoma City Wilcox Sand," *Trans.* AIME (1942) **146**, 28.
5. Leverett, M. C., and Lewis, W. B.: "Steady Flow of Gas-oil-water Mixtures through Unconsolidated Sands," *Trans.* AIME (1941) **142**, 107.
6. Muskat, Morris: *Physical Principles of Oil Production*, McGraw-Hill Book Co., 1950.
7. Kaveler, H. H.: "Engineering Features of Schuler Field and Unit Operation," *Trans.*, AIME (1944) **155**, 58.
8. Tarner, J., Evans, W. R., and Kaveler, H. H.: "Shuler Jones Sand Pool — Nine Years of Unitized Pressure-maintenance Operations," *Trans.*, AIME (1951) **192**, 121.
9. Weeks and Alexander: AAPG *Bulletin*, **26**, No. 9, 1467.
10. Sage and Lacey: *Thermodynamic Properties of the Lighter Paraffin Hydrocarbons and Nitrogen*, API Monograph on Project No. 37, 1950.
11. Beale, C.: "Viscosity of Air, Water, Natural Gas, Crude Oil and its Associated Gases at Oil-Field Temperatures and Pressures," *Trans.* AIME (1946) **165**, 94.
12. Bicher and Katz: "Viscosities of Natural Gases," *Petr. Eng.*, Reference Annual, 1944.
13. Fancher, G. H., and Mackay, D. K.: "Secondary Recovery of Petroleum in Arkansas — A Survey," Arkansas Oil and Gas Commission, El Dorado, Ark., 1946.

★★★

FEATURE ARTICLE

A PROVEN METHOD for the CONTROL of INCOMPETENT SAND FORMATIONS

H. B. RITCH
MEMBER AIME

DOWELL INCORPORATED
NEW ORLEANS, LA.

Abstract

A sand control process has been developed and field proven in the Gulf Coast. The mechanics of the application involve the use of a gel oil (or gel acid or gel water) as a vehicle to carry sand into or against the formation which has, or is expected to, produce sand. This process is carried on beneath a squeeze tool in order to cope with pressures which might otherwise be unsafe. This process makes it possible to pack a formation without mud or water contamination. After the formation is satisfactorily packed, the packing sand is held in place by a screen liner or sand consolidation plastic. Work has been done to determine the most effective packing sands and gravels. Results of this work are analyzed and tabulated.

Introduction

Sand control problems in the Gulf Coast are as old as oil production in this region. Several sand control methods have been developed; however, there have always been a few wells which defied any sand control measure. It was on wells of this type that the work described in this paper was initially done.

Many variables must be considered when the problem of sand control arises. Virtually all sand control measures are dependent on the bridging of formation particles against some screening mechanism placed in the well. This forms a filter which limits the movement of other formation solids into the well bore.

Certain basic information is desirable when preparing a sand control program:

(1) formation sand grain analysis; (2) variations in sand size in individual zones; (3) formation or producing interval thickness; (4) mechanical hookup of well; (5) subsurface depth of producing zone; (6) degree of cementation of formation; (7) lithology; (8) well fluids to be produced (viscosity); (9) bottom hole temperature and bottom hole pressure; (10) quantity of fluid production; and (11) sand control measures previously used and their success.

Some of this well information is difficult to obtain in the Gulf Coast region, due to the difficulty of recovering cores from the poorly consolidated formation.

Manuscript received in Petroleum Branch Office Aug. 10, 1954. Paper to be presented at the Petroleum Branch Fall Meeting in San Antonio, Oct. 17-20, 1954.

Laboratory Work

Previous papers[1,2] have discussed the comparative particle sizes of the formation and the controlling media, required for satisfactory sand control. A generally accepted rule of thumb involves the 10 percentile point of the formation; that is, if the controlling media will prevent the passage of 10 per cent of the largest formation particles, then adequate control usually can be obtained. The principal difficulty is in determining accurately this 10 percentile point.

Experience has shown that the very fine sands are more difficult to control than coarser formation sands. Laboratory investigations were conducted to determine the extent of migration of 200-325 mesh sand (0.0029 to 0.0017 in.) into 20-40 mesh sand (0.0331 to 0.0166 in.) and 40-60 mesh sand (0.0166 to 0.0098 in.), where these two larger graded sands were used as the controlling media. Various combinations of the 20-40 and 40-60 mesh sand were also tested.

The apparatus used in these experiments (Fig. 1) consisted of a 12-in. length of 2-in. ID pipe with screens on either end. The lower 8 in. of the pipe was packed with the controlling sand, while 200-325 mesh sand occupied the remaining 4 in. A pressure regulator on the water input line made it possible to maintain either constant flow or constant pressure. The tests were run at constant flow rates of 500 cc/sec. until a maximum pressure of 500 psi was reached, after which the tests were continued at this pressure for a total duration of six hours each. Following this, successive increments of the packing sand were screened to determine the amounts of fine sand that had penetrated into the packing sand. These data are listed in Table 1, in terms of grams of fine sand per 100 gms of packing sand found at various distances from the interface of the two sands. Table 2 records the flow rates at various times during the tests.

It is significant that the finest controlling sand (40-60 mesh) gave the best control with little, if any, penetration being experienced beyond the first 3 in. of 40-60 mesh controlling sand. However, Table 2 indicates that an apparent over-control is possible insofar as

[1]References given at end of paper.

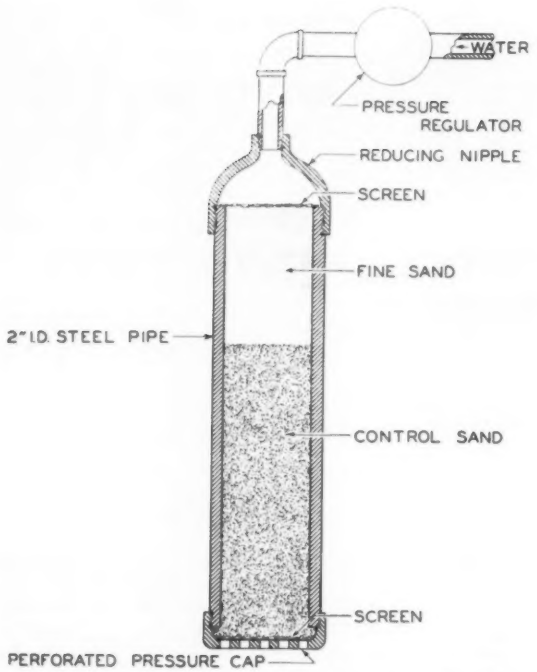


Fig. 1 — Diagram of laboratory equipment used in determining extent of penetration of fine sand into coarser packing sand.

fluid production is concerned. Thus, a happy medium must be reached if satisfactory productivity is to be maintained.

In field practice, the size range of the commonly used controlling solids is from .015-in. to .060-in. diameter. These solids are graded so that the variation in particle size is not more than .020-in. The commercial size ranges readily available are .015-.030-in., .030-.050-in., and .040-.060-in.

Types of Carriers

After the particle size range of the controlling sand has been chosen for any particular well, the mechanics of applying this material to the formation must be planned.

The use of salt water or mud as a carrying media frequently results in mud or water loss into a formation, which in turn causes production troubles in the form of unusually long clean-up periods and actual production losses. This has been avoided by the use of viscous gels as carriers for the sand or gravel.

Three types of gels were used for the sand control work described in this paper. They are gel oil, gel acid, and gel water (Fig. 2). Each is capable of holding in suspension the sand or gravel being used for sand control. These three gels make possible the selection, by the individual well owner, of a material that will satisfy the requirements of almost any well condition.

Gel Oil

Gel oil is prepared by emulsifying with water crude oil, distillate, kerosene, or similar oil. Oil constitutes approximately 97 per cent of the total volume. The emulsion formed is unstable and readily broken by (1) formation brine, (2) excess oil, or (3) formation heat.

The gel oil generally is prepared at the well, using lease crude oil. It has the advantage of rapid emulsification and, consequently, can be continuously mixed and pumped from one mixing tank. Meters are used to proportion the components accurately. The mixing speed is usually dependent on the rate at which the crude oil can be pumped from the tank battery. This gel is a high fluid-loss material that will carry sand in quantities up to 5 lbs/gal.

Gel Acid

Gel acid is prepared by emulsifying kerosene and hydrochloric acid. This emulsion is readily broken: (1) by movement through a porous media, (2) by formation heat, or (3) by the acid reacting with the formation. Gel acid also is a high fluid-loss material that can satisfactorily suspend sand in quantities up to 5 lbs/gal.

Gel Water

Gel water is a gel prepared by adding a thickening agent to salt water, fresh water, or hydrochloric acid. The viscosity can be controlled and may run as high as several thousand centipoises. The gel is miscible with water and is broken by formation heat or bacterial action. The fluid loss of this material, as well as its sand carrying qualities, are dependent on the viscosity of the gel.

Gel oil and gel water can be prepared at the well site, whereas, gel acid customarily is carried to the well site in tank trucks. Gel oil is the most commonly used fluid of the three.

Mechanics of Treating Formation

The subject well should be cleaned out to bottom. Some companies attempt to wash the perforated interval until no more formation sand can be detected in the workover fluid. This condition is never realized in some wells, which would indicate that a cavity is not being formed but rather that the formation is heaving or sloughing. It is not known if it is possible to create a cavity, and there is not proof that it is necessary. Some well operators do not like to wash perforations, especially if thin beds of shale and sand are present in the perforated interval. This is because of the pos-

TABLE 1 – PENETRATION OF FINE SAND (200-325 MESH*) INTO A COLUMN OF PACKING SAND (IN GRAMS OF FINE SAND PER 100 GMS OF PACKING SAND).

Composition of Packing Sand	Distance of Penetration into Packing Sand						
	½"	1"	2"	3"	4"	5"	8"
100 per cent 20-40 mesh	8.40	3.90	0.96	0.57	0.39	0.27	0.18
70 per cent 20-40; 25 per cent 40-60	6.28	1.58	0.59	0.35	0.22	0.14	0.09
50 per cent 20-40; 50 per cent 40-60	1.60	0.53	0.29	0.18	0.12	0.10	0.08
25 per cent 20-40; 75 per cent 40-60	1.35	0.43	0.205	0.13	0.08	0.06	0.05
100 per cent 40-60 mesh	1.025	0.40	0.195	0.09	0.05	0.05	0.05

*NOTE: Mesh sizes refer to U. S. standard sieve sizes.

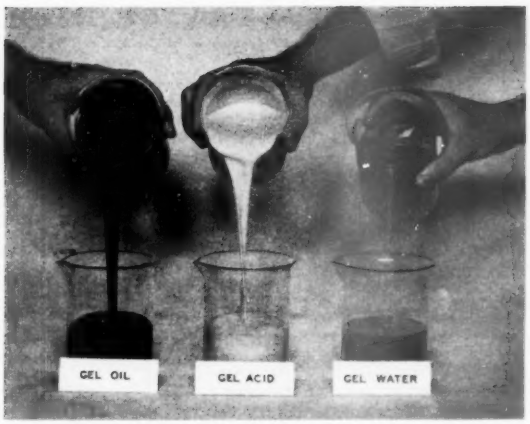


Fig. 2 — Various types of thickened carrying fluids are available for suspending control sand during packing operations.

sibility of washing the sand from between the shale streaks, thereby allowing the shale to cover the potential producing sand. Experience indicates that in some cases this condition may have developed.

Running the Squeeze Tool

Following the clean out, a squeeze tool is run, either on tubing or drill pipe. Tailpipe generally is used so the tubing or drill pipe may be lowered to the bottom of the well without the squeeze tool passing through the perforated interval. This is merely a precautionary measure and is not absolutely necessary. The purpose of tagging bottom is to determine whether any formation sand has moved into the well during the round tripping of the tubing. If any sand is detected, it is removed by reverse circulation.

Next, the tubing is raised and the squeeze tool set, with the bottom of the tailpipe 3 to 4 ft above the top perforation. If it is not desirable to squeeze any of the workover fluid into the formation, oil or salt water can be spotted over the perforated interval prior to the raising and setting of the squeeze tool. A small amount of fluid should be pumped into the formation prior to the squeeze to make sure the perforations are open and determine what the initial injection rate will be. This information is used to determine the concentration of sand (pounds of sand per gallon of gel carrier) that will be used.

Fig. 3 — Mobile equipment used for sand control treatments includes transport and mixing tanks, and heavy duty pumps and lines.

Mixing Gel Oil

Gel and sand are then mixed in cylindrical tanks equipped with power-driven paddle-mixers (Fig. 3). Agitation is necessary to form the emulsion and distribute the sand through it uniformly.

The gel-sand mixture is then pumped down the tubing by means of a triplex pump. As soon as the mixture has been spotted, the squeeze tool circulating mechanism is closed and the squeeze begun.

If the well is a shallow one, a continuous mixing and pumping procedure is generally used. From 1 to 2 lbs sand/gal. of gel has been found to be the most satisfactory concentration, in most cases. However, on wells which are taking large quantities of sand at relatively low squeeze pressures, it may be desirable to increase the sand concentration to as much as 5 lbs sand/gal of gel.

On deeper wells the batch method is frequently used. Twelve to 24 bbls of sand and gel are mixed, spotted to bottom and squeezed. This procedure is repeated until no more sand can be squeezed away.

Squeezing

Whichever method is used, the purpose is to squeeze into or against the formation all the sand that can be put away under a maximum arbitrary pressure. It is then advisable to release the squeeze tool and clean out by reverse circulation any sand left inside the casing. This is done as rapidly as possible to keep from

TABLE 2 — FLOW RATES RECORDED DURING SAND PENETRATION TESTS.

	Composition of Packing Sand									
	100 per cent 20-40 mesh		75 per cent 20-40, 25 per cent 40-60 mesh		50 per cent 20-40, 50 per cent 40-60 mesh		25 per cent 20-40, 75 per cent 40-60 mesh		100 per cent 40-60 mesh	
	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure
Time	(Ml/min)	(psi)	(Ml/min)	(psi)	(Ml/min)	(psi)	(Ml/min)	(psi)	(Ml/min)	(psi)
10 minutes	500	.....	500	15	500	20	500	15	500	25
15 minutes	500	40	500	35	500	50	500	60	.....	.....
30 minutes	500	350	500	125	500	400	500	350	500	315
1 hour	500	320	500	290	500	500	350	500	250	500
1½ hours	500	290	500	500	225	500	85	500	80	500
2 hours	500	290	200	500	105	500	60	500	150	500
2½ hours	500	290	100	500	80	500	55	500	60	500
3 hours	500	280	130	500	67	500	35	500	45	500
3½ hours	135	500	120	500	65	500	45	500	40	500
4 hours	200	500	75	500	60	500	35	500	45	500
4½ hours	150	500	85	500	43	500	35	500	60	500
5 hours	125	500	35	500	87	500	25	500	85	500
5½ hours	115	500	70	500	55	500	35	500	65	500
6 hours	115	500	70	500	50	500	35	500	35	500

TABLE 3 — RESULTS OF TYPICAL SAND CONTROL TREATMENTS IN GULF COAST AREA. ALL WELLS SHOWN HAD SANDED UP PRIOR TO TREATMENT.

Well	County-State	Field	Pounds of Sand or Gravel Used	Gallons of Gel Used	Production Following Sand Control Treatment
A	LaFourche, La.	Golden Meadow	5,000	2,000	140 BOPD-sand free
B	LaFourche, La.	Bay Marchand	16,000	3,500	120 BOPD-30 BWPD-trace sand
C	LaFourche, La.	Timbalier Bay	5,100	1,000	194 BOPD-sand free
D	LaFourche, La.	Valentine	6,000	2,000	600 BWPD-10 BOPD-no sand
E	LaFourche, La.	Lake Long	7,000	2,000	65 BOPD-2693 MCF gas-no sand
F	Jefferson, La.	Bayou Perot	2,000	1,000	3 BOPD-2309 MCF gas-no sand
G	Jefferson, La.	Grand Isle	14,500	4,850	300 BOPD-sand free
H	Plaquemine, La.	Grand Bay	6,500	2,000	192 BOPD-24 per cent water-no sand
I	Plaquemine, La.	Main Pass	4,300	1,500	167 BOPD-sand free
J	Assumption, La.	Napoleonville	1,800	1,000	145 BOPD-1 per cent water-no sand
K	Calcasieu, La.	Ged	16,700	4,000	60 BOPD-10 BWPD-no sand
L	New Iberia, La.	Little Bayou	4,200	1,260	30 BOPD-sand free
M	Cameron, La.	Cameron Meadows	2,500	500	1,000 BWPD-trace oil-no sand
N	Arcadia, La.	North Crowley	2,900	1,000	750 MCF gas-sand free
O	Victoria, Tex.	Bloomington	21,000	6,000	48 BOPD-48 BWPD-no sand
P	Harris, Tex.	South Houston	10,000	3,000	90 BOPD-sand free
Q	Harris, Tex.	Goose Creek	9,000	6,000	141 BOPD-sand free
R	Duval, Tex.	Hagist Ranch	6,000	2,000	40 BOPD-sand free
S	Jefferson, Tex.	Clam Lake	10,500	3,000	155 BOPD-117 BWPD-no sand
T	Jefferson, Tex.	Spindle Top	10,100	3,000	123 BOPD-3 BWPD-no-sand

washing out the sand which has just been squeezed through the perforations.

If maximum pressure was reached before the desired quantity of sand was displaced, the squeeze tool should be reset and a small batch (usually 12 bbls) of gel and sand spotted to bottom and squeezed, if possible. This is a precautionary measure to make certain that the formation is well packed and did not bridge prematurely.

Many different interpretations have been made of pressure changes occurring during a squeeze. Experience has shown that if a formation is taking sand and gel at a given pressure, a sudden pressure increase of more than 300 or 400 lbs indicates the formation will take little, if any, more sand. Apparently, the void space has been filled and the abrupt pressure rise indicates a fill-up inside the casing, over the perforated interval.

After the formation is packed, a screen liner is generally run and additional sand is packed between the liner and perforated casing. A number of different types of screens and liners are available. Should well conditions such as very small casing or liners, partially collapsed casing, etc., prevent the use of a screen liner, sand consolidation plastic has been used successfully.

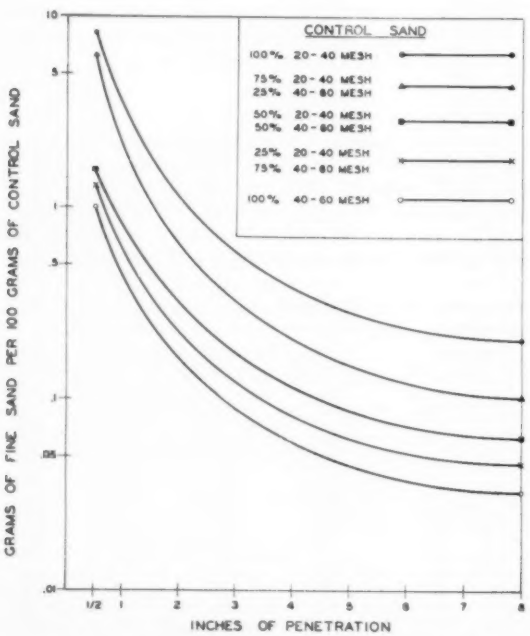


Fig. 4 — Penetration of Fine Sand into Graded Control Sand.

Results

These sand control procedures have been employed in many wells in the Gulf Coast area. Table 3 lists the results that have been obtained on a number of these treatments. This method has resulted in successful control of formation sand in approximately 85 per cent of the wells treated.

This technique has a number of advantages over other sand packing methods. It can be seen that little, if any, fluid other than the gel will enter the formation, using this procedure. Large quantities of sand can be placed into or against the formation in a minimum amount of time. As a result, rig, service company and other workover expenses are much lower. By using a squeeze tool and high pressure pump it is possible to apply whatever pressure, within reason, is necessary to force the sand through the perforations. On the other hand, these same tools are ideal for wells on vacuum to prevent loss of undesirable well fluids into the formation. The gel carrier minimizes the possibility of solids bridging in the tubing and makes it possible to reverse out easily after maximum pressure has been reached. High fluid velocities are not necessary to cause the sand particles to move through the perforations. Cleanup time is materially reduced, due to the smaller amounts of fluid required by this method.

Acknowledgment

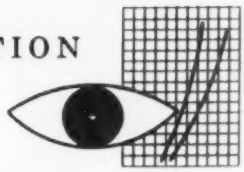
Appreciation is expressed to R. B. Rosene and G. W. Woodard for furnishing laboratory data used in the preparation of this article.

References

1. Coberly, C. J., and Wagner, E. M.: "Some Considerations in the Selection and Installation of Gravel Pack for Oil Wells," TP 960, *Petr. Tech.*, August, 1938.
2. Gumpertz, Ben: "Screening Effect of Gravel on Unconsolidated Sands," *Trans.* AIME (1941), 142, 76.

★★★

REPORT and INTERPRETATION



VIRGINIA BEILHARZ

ASSISTANT SECRETARY
PETROLEUM BRANCH, AIME

In recent months the Petroleum Branch has had an increasing number of inquiries about reinstatement of membership. Extensive membership promotion activities this year and the formation of several new local sections have regenerated interest among many former members. Reinstatement applications are now about 14 per cent of total new applications.

The regulations governing reinstatement change from time to time, and the current rulings are reviewed below, so that members can assist their friends who may be interested in reinstatement. Certain procedures regarding change of status, inactive status, and other membership matters are also outlined for the convenience of members.

Reinstatement Procedure

An application for reinstatement should be submitted on the standard application-for-membership form. The Admissions Committee must have all information requested on the form to reinstate a member, and it must be endorsed by three AIME members.

Current dues are prorated from the month of election, both for reinstatements and new members. Thus, a man elected in October owes only one-fourth of the annual dues for that year. If he is elected to full Member or Associate Member, for example, an October election would pay $5 current dues; a Junior Member would pay $3.

Reinstatement normally establishes the election date as the date of reinstatement. To restore his original election date, a former member must pay all back dues.

Resignations

A member of any grade who resigned in good standing when he terminated his membership may reinstate by paying only the current dues, prorated from the month of election as indicated above. A member may resign at any time before April 1 of a given year without becoming liable for that year's dues. If a change of status to full Member or Associate Member is involved in his reinstatement, he must pay the initiation fee.

Members Dropped for Non-payment

If a member does not resign, but simply lets his dues payment lapse, he is carried for two years in arrears. His publications are suspended after March of the first year for which he fails to pay dues. At the end of two years, he is dropped from the rolls. The regulations outlined in the accompanying table govern reinstatements for members who have been dropped for non-payment of dues. The rules are designed to provide that reinstatement will never cost more than $20 plus current dues.

Special Reinstatement

A special reinstatement may be made within the year in which the member is dropped, without filing a new application. All back dues must be paid, and the member is entitled to back copies of the JOURNAL OF PETROLEUM TECHNOLOGY which are available upon request. His original election date will be restored, and he is entitled to the $2 annual credit on the initiation fee for continuous paid membership, if applicable.

Installment Payment and Credits Toward Initiation Fee

An initiation fee of $20 is required of all Members and Associates. The initiation fee can be paid in four annual installments of $5 each if the member wishes.

Upon transfer to Member or Associate Member, a Junior Member is entitled to $2 credit towards the initiation fee for each year of continuous paid membership as a Junior Member or Student Associate. Thus, a Junior Member who has been continuously on the rolls for 10 years will have his initiation fee cancelled entirely. If he should let his membership lapse, however, he must pay all back dues to receive these credits.

Non-members who attend the Petroleum Branch Fall Meeting in October can apply $5 of the non-member registration fee toward the initiation fee, if they apply for membership within 30 days after the meeting.

Inactive Status for Military Service

A member who enters military service may apply for inactive status and remain on the rolls without payment of dues and without receiving publications. Even though he pays no dues, he accumulates the $2 annual credit on the initiation fee for continuous membership. When he is released from service, he reactivates his membership upon request, without filing an application.

Change of Status Procedure

Student Associates are now automatically transferred to Junior Member status at the end of the year in which they graduate, and no application is necessary. If a Student Associate fails to accept his Junior Membership by payment of dues, he is dropped in good standing. If his graduation date is changed from the one submitted on his application, the Institute should be notified.

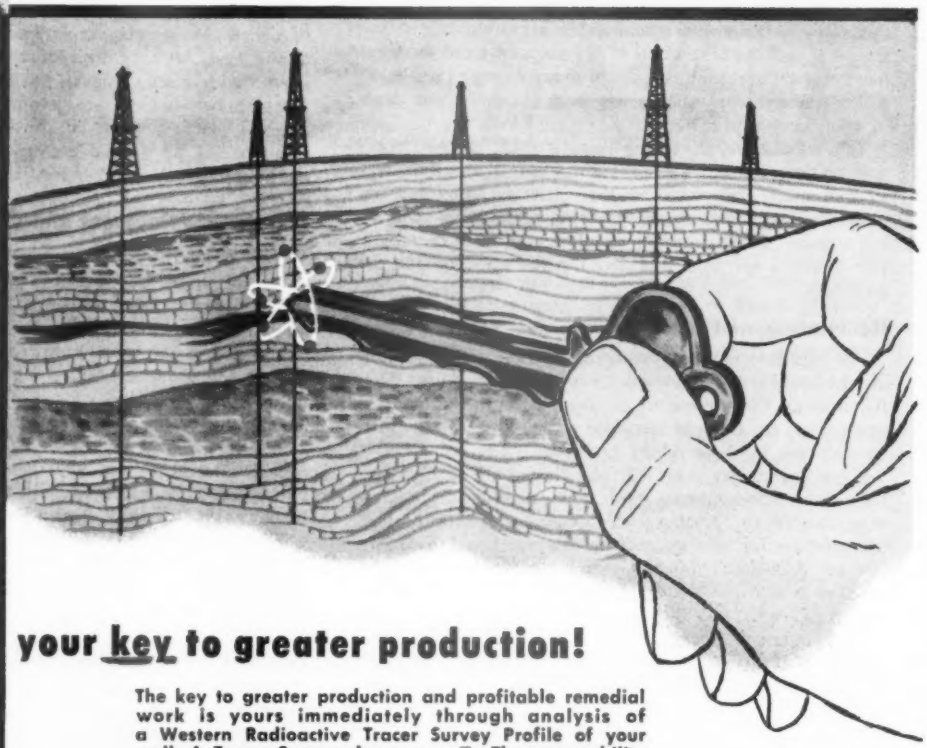
Junior Members are automatically transferred to Associate Membership at the end of the year in which they reach 33 years of age. A complete application, with full professional experience record and three member endorsements, must be submitted if he wishes to transfer to full Member.

REINSTATEMENT REQUIREMENTS FOR MEMBERS DROPPED FOR NON-PAYMENT OF DUES

Former Grade of Membership	Grade in Which Reinstated: Junior Member	Grade in Which Reinstated: Associate or Member
Student Associate	No arrears. Pays only current dues, prorated.	No arrears. Pays initiation fee and current dues, prorated.
Junior Member	If dropped with two years' arrears, owes $24. Must pay only $20 and current dues, prorated.	Arrears will be cancelled upon payment of initiation fee and current dues, prorated.
Associate or Member		Has already paid initiation fee. If dropped with two years' arrears, owes $40. Must pay only $20 of this, plus current dues, prorated. ★★★

WESTERN "Tracer Survey"

FOR ACCURATE SUBSURFACE DATA



your key to greater production!

The key to greater production and profitable remedial work is yours immediately through analysis of a Western Radioactive Tracer Survey Profile of your well. A Tracer Survey shows you: The permeability picture, communications between perforations and zones behind casing, casing shoe and pipe leaks, location of blocking materials, zones selectively acidized previously, fractured zones, best formation packer seats, cement tops.

By adding radioactive particles to fluid and pumping it into your well, a subsequent Gamma Ray Investigative curve will give you an accurate analysis of subsurface conditions.

Western Tracer Surveys, therefore, will guide you accurately in completion and remedial work and, in addition, also will help you solve many down-hole difficulties.

Recordings of story-telling radiations are made on Western's regular "PROVED-ACCURACY" GAMMATRON instruments and can be run in either casing or tubing. Painstaking analysis of every profile is made by specially trained and experienced engineers.

Consult with a Western Engineer on the many ways WESTERN RADIOACTIVE TRACER SURVEYS can serve you . . . and save you money!

THE WESTERN COMPANY

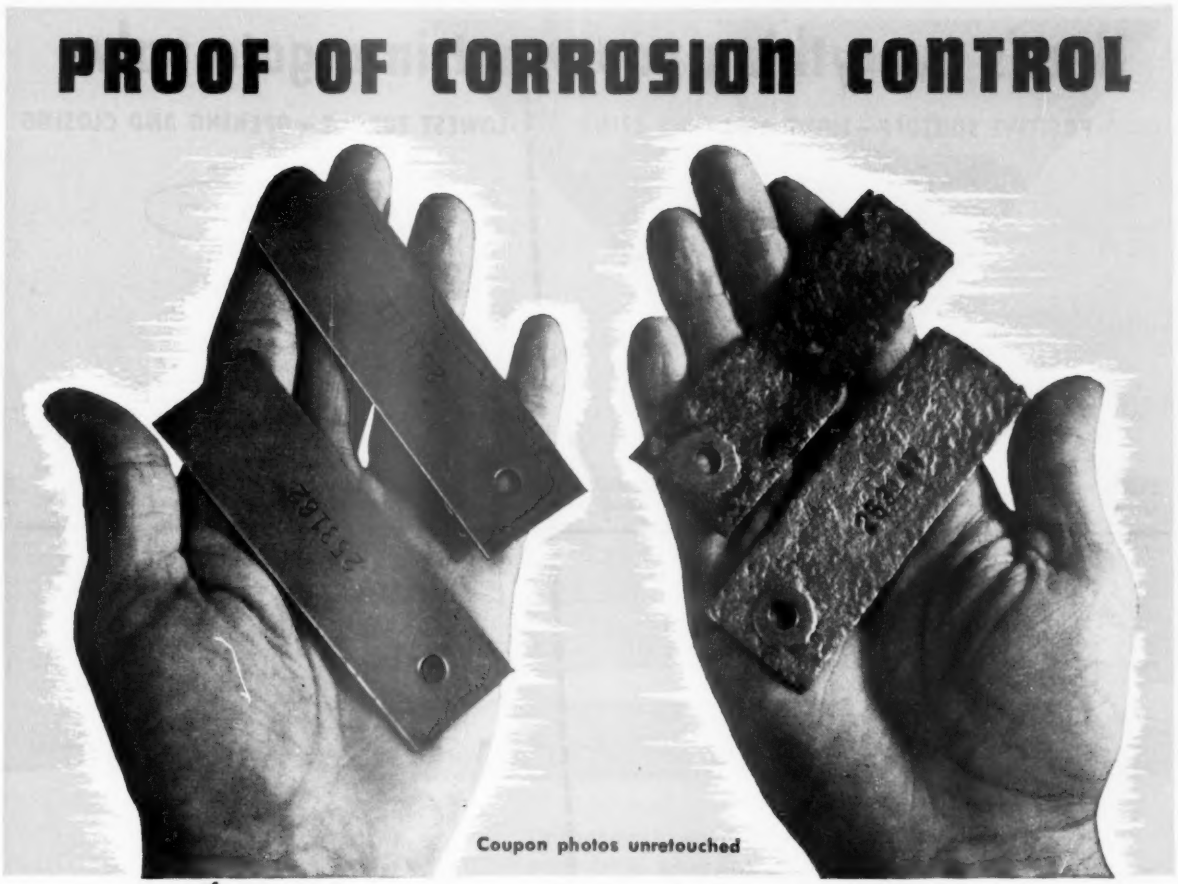
General Offices:
Midland, Texas

Engineered Well Services

ACIDIZING
PERFORATING
Jet and Bullet

FRACTURIZING
GAMMATRON
Radioactivity Well Logging

PROOF OF CORROSION CONTROL



Coupon photos unretouched

with *Visco*® ANTI-CORROSION TREATMENT

IT took only 30 days for the two steel coupons shown at right above to corrode almost away in the stream of a secondary-recovery well in Kansas. Both coupons, where not corroded through, are wafer thin. An anti-corrosion chemical was being fed at the rate of one pint per day, yet the average corrosion rate on the coupons was 216 mils* per year.

In the same well, Visco-treated with the same amount of chemical per day, the coupons at left above showed a corrosion rate of only 8.1 mils per year after 29 days' exposure.

Visco Chemicals cut the corrosion rate over 96%!

For corrosion control *results* and treating *economy*, call your Visco Representative, *now*.

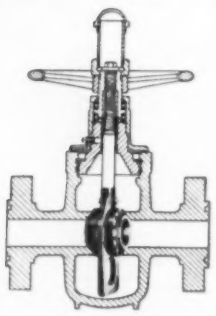
*1 mil=.001 inch. A corrosion rate of 216 mils per year means that the corrosive attack, if uniform, would have corroded away the entire surface of the metal to a depth of .216 inches in a year. However, the real danger of high corrosion rates, as the coupon shows, is the much deeper and faster penetration occurring at localized areas.

VISCO PRODUCTS COMPANY
INCORPORATED
2600 Nottingham at Kirby, Houston 5, Texas
Telephone: MAdison 0433

Visco. . . CONSISTENTLY EFFICIENT OIL INDUSTRY CHEMICALS

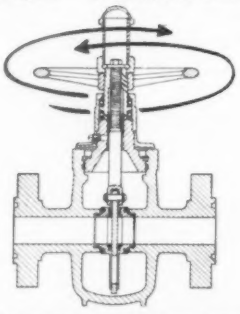
Here's everything you want in a gate valve

POSITIVE SHUTOFF—TIGHT AS A LINE BLIND



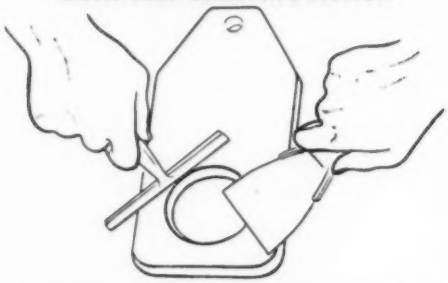
Positive dead-tight seal with pressure on either side of gate. Grove Seal-"O"-Ring Gate Valves also serve as a line blind.

LOWEST TORQUE—OPENING AND CLOSING



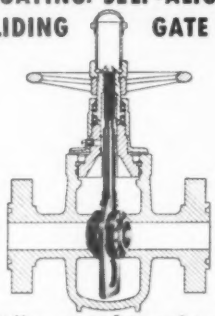
Parallel-sided full-opening port plate is non-wedging, non-galling, non-distorting. Torque required to open or close valve is less than other types of gate valves.

DUAL SELF-CLEANING ACTION



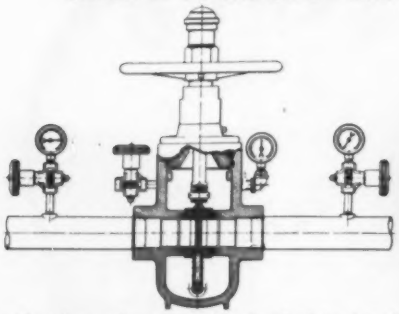
Steel seat assemblies and resilient "O" ring seals are in constant contact with full-opening port plate. Seating surfaces are stripped clean, squeegeed and polished with each operation.

FULL-FLOATING, SELF-ALIGNING FREE-SLIDING GATE ACTION

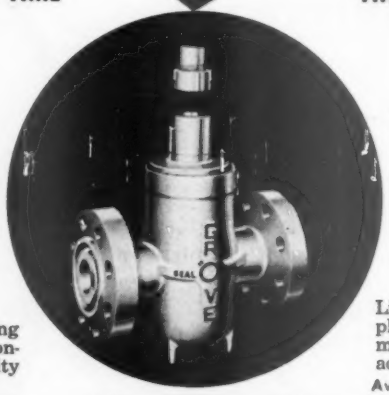


Open, closed or throttling, port-plate and seats are free-floating for perfect self-alignment, constant dead-tight seal, easy sliding action, imposing no strain or stress.

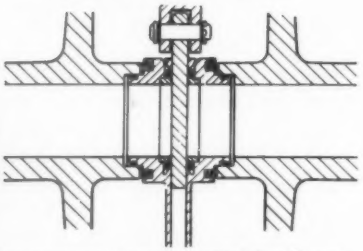
CHECK IT IN THE LINE—ANY TIME



Freedom of gate can be checked by turning hand-wheel, without "breaking" the seal. Non-variance of gauge pressure on body cavity verifies dead-tight seal of valve.



THE GREATER THE PRESSURE THE TIGHTER THE SEAL



Line pressure forces parallel-faced port plate against seat assemblies for positive metal-to-metal seal plus dual sealing action of resilient "O" rings.

Available through leading oil field supply houses

GROVE SEAL-"O"-RING Gate Valves

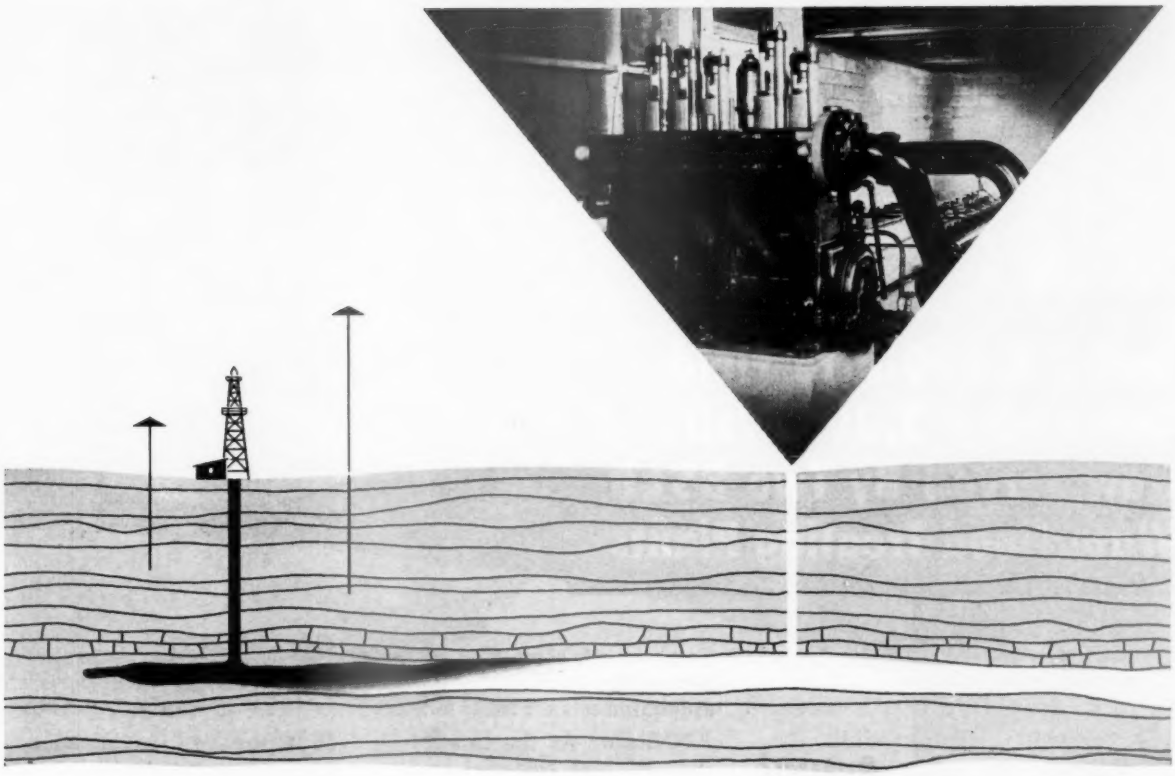
GROVE REGULATOR COMPANY • 65th & Hollis Sts., Oakland 8, California

HOUSTON 4—1901 Calumet St. • **LOS ANGELES 6**—1930 W. Olympic Blvd. • **NEW YORK 17**—415 Lexington Ave.

GROVE
SIMPLICITY
ACCURACY
SAFETY

S-404

CORPUS CHRISTI, TEXAS	ODESSA, TEXAS	TULSA, OKLAHOMA	LAFAYETTE, LA.	NEW ORLEANS, LA.	DENVER, COLO.
4534 No. Baldwin Blvd.	114 N. Washington St.	318 Thompson Bldg.	Scott Road	504 Delta Bldg.	2669 Cherry St.



USE ALDRICH Direct Flow pumps for water flooding

Outstandingly satisfactory performance at varying pressures in water flood installations throughout the country gives proof of quality.

- *high speed*—greater volume from more compact pumps.
- *low maintenance costs*—KOSMOS Porcelain Plungers and completely sectionalized fluid-ends reduce maintenance, material costs and down time.
- *complete range of sizes*—3″ Triplex, 5″ and 6″ Triplex and Multiplex units permit optimum combinations of pumps with maximum interchangeability of parts.
- *for corrosive service*—fluid-ends available in stainless steel or aluminum bronze.

Ask for proof of performance in any field.

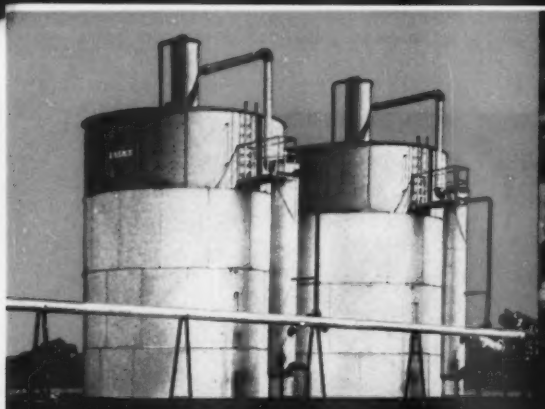
the ALDRICH *pump company*

. . . Originators of the Direct Flow Pump

30 PINE STREET • ALLENTOWN, PENNSYLVANIA

Representatives: Bushnell Controls & Equipment Co., Inc., 5137 West Jefferson Blvd., Los Angeles 16, Calif. • Cross Pump & Equipment Co., P.O. Box 889, Charleston 23, W. Va. • Lloyd T. Gibbs Co., 1021 Petroleum Bldg., Tulsa 3, Okla. • R. B. Moore Supply Co., Bolivar, N. Y. • Walter Norris Engineering Co., Civic Opera Bldg., 20 North Wacker Drive, Chicago 6, Ill. • Power Specialty Co., P.O. Box 6365, 2000 Kipling Street, Houston 6, Texas; The Suburban Bldg., Room 204, 5526 Dyer Street, Dallas 6, Texas • B. G. Harmon Service & Equipment Co., P. O. Box 309 (Farm Bureau Bldg.), Carmi, Ill. • Stearns-Roger Manufacturing Co., 1720 California Street, Denver 2, Colo. • Export: Petroleum Machinery Corporation, 30 Rockefeller Plaza, New York 20, N. Y.

Direct Flow Spare Parts Stock—at Carmi, Ill., Houston, Los Angeles, Odessa, and Tulsa



Entire 8,800-Acre Field Containing 2,300 Wells Now Served By Two BS&B Waterflood Treating Plants

An Actual Case History From Our Files

Two recently completed BS&B Waterflood Treating Plants are now serving the operators* of the unitized Lake Centralia-Salem Oil Field, approximately 6½ miles long and 2½ miles wide, in southern Illinois.

PROBLEM: At the time of unitization, this field contained more than 365 tank batteries servicing approximately 2,300 wells. Most of these tank batteries were 10 years old or more, and with gas depletion and the necessity for installing gathering lines for waterflooding, a unique treating problem was presented.

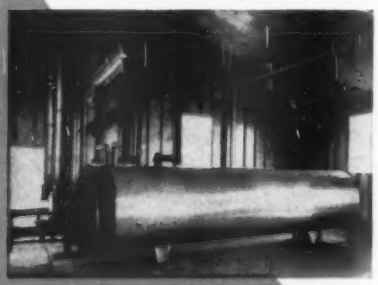
SOLUTION: It was decided to consolidate the entire production through two large treating plants, each of which was to have an initial design capacity of 10,000 BOPD and 35,000 BWPD, with an ultimate capacity of 30,000 BOPD and 115,000 BWPD. Each plant was to consist of the following basic items of equipment:

1 BS&B 10' x 28' Freewater Knockout
2 BS&B 70LSH Steam Generators
2 BS&B 30" x 21' x 6" Heat Exchangers
2 BS&B 21'-6" x 32'-2" 2,000 Bbl. Settling Tanks
4 BS&B 38'-7⅞" x 24'-1½" 5,000 Bbl. Stock Tanks

Plants were to be so constructed that equipment could be added or removed without interrupting operations. Water of 1.05 specific gravity was to be removed from oil of approximately 37° API.

RESULT: Test results on these plants have been most satisfactory. Heat exchangers were transferring 2,000,000 BTU/Hr./heat exchanger under medium load with only one steam generator firing. Water carry over from the freewater knockout was less than 1%. The grind outs do not exceed .002 to .003%.

* Name supplied on request.

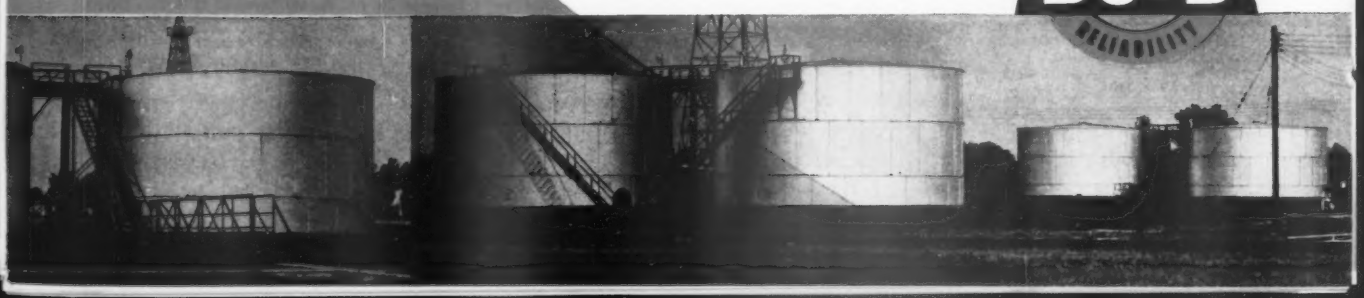


BLACK, SIVALLS & BRYSON, INC.

Oil & Gas Equipment Division, Dept. I-BL9

1708 West Main Street • Oklahoma City, Oklahoma

EFFICIENCY OVER 60 YEARS BS&B RELIABILITY



Security

drilling *Equipment*

3-CUTTER ROCK BITS

THOROUGH RESEARCH DEVELOPED THEM

MASTER CRAFTSMEN PRODUCED THEM

FIELD-TESTING HAS PROVED THEM

Progress in the Petroleum Industry hinges on new equipment and new techniques. With them Industry moves forward, sharpening efficiency, trimming costs. Two *field-proven* achievements in this forward march are Security's Neo-Red Rubber Stabilizer and 3-Cutter Rock Bits. With them, advanced drilling techniques have become every-day practice.

To learn more about these and other rugged Security drilling equipment, contact your Security field man today.

NEO-RED RUBBER STABILIZERS

GET Security IN DRILLING

ENGINEERING DIVISION

ONE OF THE DRESSER INDUSTRIES

ROCK BITS • REAMERS • HOLE OPENERS • CASING SCRAPERS • SECURALOY

Main Office: WHITTIER, CALIF.—EXPORT: CHANIN BLDG., N. Y.C.
Plants: WHITTIER, CALIF.—DALLAS, TEXAS

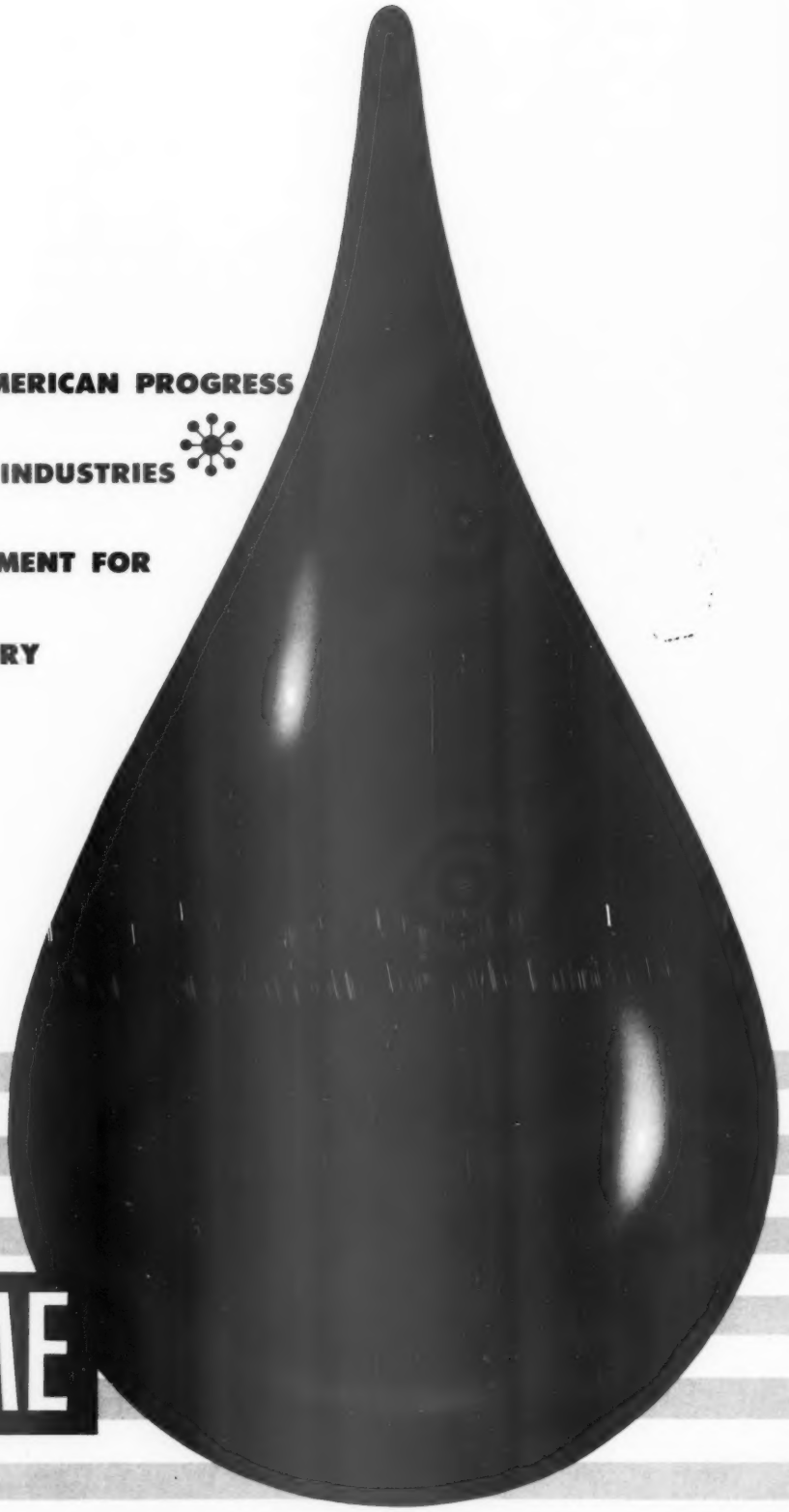
Branches in All Major Producing Areas

OIL...BASIC TO AMERICAN PROGRESS

DRESSER INDUSTRIES

...BASIC EQUIPMENT FOR

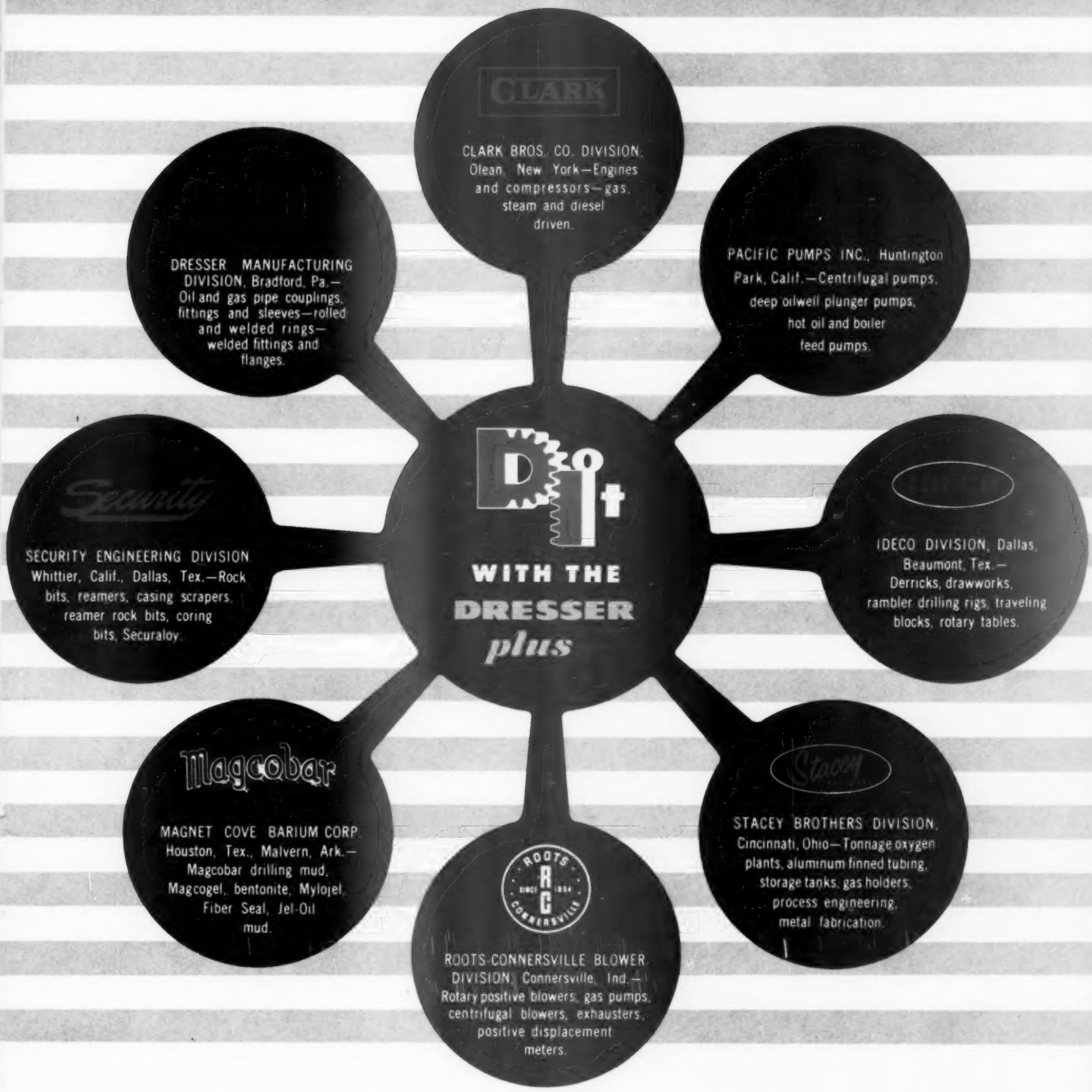
THE OIL INDUSTRY



Greetings–

AIME

Printed in U. S. A.


CLARK
CLARK BROS. CO. DIVISION, Olean, New York—Engines and compressors—gas, steam and diesel driven.
DRESSER MANUFACTURING DIVISION, Bradford, Pa.—Oil and gas pipe couplings, fittings and sleeves—rolled and welded rings—welded fittings and flanges.
PACIFIC PUMPS INC., Huntington Park, Calif.—Centrifugal pumps, deep oilwell plunger pumps, hot oil and boiler feed pumps.
Security
SECURITY ENGINEERING DIVISION Whittier, Calif., Dallas, Tex.—Rock bits, reamers, casing scrapers, reamer rock bits, coring bits, Securaloy.
DI
WITH THE DRESSER plus
IDECO DIVISION, Dallas, Beaumont, Tex.—Derricks, drawworks, rambler drilling rigs, traveling blocks, rotary tables.
Magcobar
MAGNET COVE BARIUM CORP. Houston, Tex., Malvern, Ark.—Magcobar drilling mud, Magcogel, bentonite, Mylojel, Fiber Seal, Jel-Oil mud.
Stacey
STACEY BROTHERS DIVISION, Cincinnati, Ohio—Tonnage oxygen plants, aluminum finned tubing, storage tanks, gas holders, process engineering, metal fabrication.
ROOTS CONNERSVILLE
ROOTS-CONNERSVILLE BLOWER DIVISION, Connersville, Ind.—Rotary positive blowers, gas pumps, centrifugal blowers, exhausters, positive displacement meters.

Use any Dresser product and put the DRESSER *plus* + to work for you!

Every day, petroleum plays an increasingly important part in providing the basic energy for this nation's unequalled industrial potential. And the companies that make up Dresser Industries continue to provide more and more of the basic equipment used by the great petroleum industry in the unfailing performance of its responsibilities as a public servant. In every phase of the oil industry – from drilling to distribution – the Dresser companies work together to supply these equipment needs.

When you use any Dresser product, you get an important added value . . . the DRESSER PLUS + . . . the coordinated research and combined engineering talent of all the Dresser companies directed toward one goal: to make certain that every Dresser product continues to be *a standard of comparison the world over.*

DRESSER INDUSTRIES, INC.
OIL, GAS AND CHEMICAL EQUIPMENT

ATLANTIC BUILDING • DALLAS, TEXAS

Now—every well can have the SAFETY ADVANTAGE of HYDRIL Blowout Prevention Control!

NEW

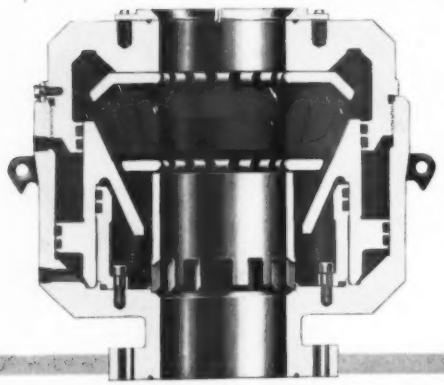
HYDRIL

"MSP-2000"

BLOWOUT

PREVENTER

PATENTED



Compact and lightweight, this new Hydril "MSP-2000" Blowout Preventer is especially suitable for low- and medium-pressure drilling, remedial work and well servicing. With the same cartridge-type packing unit as the famous Hydril "GK" Preventer, the "MSP-2000" acts instantly to control rising well pressures. Designed to operate with the Hydril Automatic Pump Accumulator and remote control manifold.

For complete information, write or wire Hydril Company, or see your nearest Hydril representative.

HYDRIL COMPANY

714 West Olympic Boulevard, Los Angeles 15, California

Factories: Los Angeles, Calif.; Houston, Texas; Youngstown, Ohio; Rochester, Pa.

SALES OFFICES: Bakersfield, Los Angeles, Ventura, Calif.; Harvey, New Iberia, La.; Youngstown, O.; Tulsa, Okla.; Rochester, Pa.; Corpus Christi, Dallas, Houston, Midland, Odessa, Tex.; Casper, Wyo.; Calgary, Edmonton, Canada

MEETING INFORMATION SECTION

of the

PETROLEUM BRANCH
AMERICAN INSTITUTE
OF
MINING AND METALLURGICAL ENGINEERS

ANNUAL FALL MEETING

San Antonio, Texas **October 17-20, 1954**

PROGRAM
of
Papers and Activities
PETROLEUM BRANCH, AIME, FALL MEEETING

(All papers shown are subject to change or withdrawal)

Sunday, October 17

1:00 p.m. to 6:00 p.m. — ADVANCE REGISTRATION — Ballroom, Plaza Hotel

2:00 p.m. to 5:00 p.m. — PETROLEUM SECTION CONFERENCE — Roof Garden, Plaza Hotel, Kenneth B. Ford, Conference Chairman, Presiding

Monday, October 18

8:00 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS — Ballroom, Plaza Hotel

9:00 a.m. to 11:15 a.m. — FIELD CASE HISTORIES — Roof Garden, Plaza Hotel

379-G: *A Study of the West Cement Medrano Unit — Caddo County, Oklahoma,* by ALVIN E. HALL, Phillips Petroleum Co.

380-G: *Pressure Maintenance by Inert Gas Injection in the High Relief Elk Basin Field,* by D. L. GARTHWAITE, FLOYD KREBILL, and F. M. STEWART, Stanolind Oil and Gas Co.

9:00 a.m. to 11:30 a.m. — LOGGING — Ballroom, Gunter Hotel

400-G: *A Subsurface Flowmeter,* by R. C. RUMBLE, Humble Oil and Refining Co.

401-G: *A Method for Neutron-Derived Porosity for Thin Beds,* by J. M. EDWARDS and A. L. SIMPSON, McCullough Tool Co.

402-G: *A Study of Electric Log Interpretation Methods in Shaly Formations,* by LEENDERT DE WITTE, Continental Oil Co.

9:30 a.m. to 11:15 a.m. — GAS ENGINEERING AND INJECTION — Aztec Theater

365-G: *The Phase and Volumetric Behavior of Natural Gases at Low Temperatures,* by FRED KURATA, P. C. DAVIS, A. F. BERTUZZI, and T. L. GORE, University of Kansas.

423-G: *Secondary Recovery Operations in Tijerina No. 3 Unit Reservoir Tijerina-Canales-Blucher Field, Jim Wells County, Texas,* by N. A. OLANSEN, The Texas Co.

10:00 a.m. to 12:00 m. — For the Ladies — WELCOMING COFFEE — Brackenridge Park

12:15 p.m. — PETROLEUM BRANCH WELCOMING LUNCHEON — Roof Garden, Plaza Hotel, Paul R. Turnbull, Luncheon Chairman, Presiding

2:30 p.m. to 5:00 p.m. — LABORATORY METHODS — Ballroom, Gunter Hotel

408-G: *Effect of Aging of East Texas Cores on Results of Laboratory Determinations,* by J. S. OSOBA, Humble Oil and Refining Co.

409-G: *A Study of Water Flood Efficiency in Oil-Wet Systems,* by J. E. WARREN and JOHN C. CALHOUN, JR., The Pennsylvania State University.

410-G: *The Role of Bubble Formation in Oil Recovery by Solution Gas Drives in Limestones,* by C. R. STEWART, E. B. HUNT, JR., F. N. SCHNEIDER, T. M. GEFFEN, and V. J. BERRY, JR., Stanolind Oil and Gas Co.

2:30 p.m. to 5:00 p.m. — PRODUCTION OPERATIONS — Roof Garden, Plaza Hotel

381-G: *External Casing Corrosion Control,* by J. D. SUDBURY, J. E. LANDERS, and D. A. SHOCK, Continental Oil Co.

382-G: *Remote Automatic Control of Oil Production,* by C. R. BAYLESS and J. W. DAUGHTREY, Gulf Oil Corp.

383-G: *Where Corrosion Control Stands Today,* by H. L. BILHARTZ, Production Profits, Inc.

425-G: *Corrosion of Oil Well Casing by Earth Currents,* by LEENDERT DE WITTE and F. J. RADD, Continental Oil Co.

6:30 p.m. to 10:30 p.m. — PETROLEUM BRANCH BARBECUE SUPPER and FRONTIER PARTY — McArthur Park, San Antonio

Tuesday, October 19

8:00 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS — Ballroom, Plaza Hotel

9:00 a.m. to 11:15 a.m. — RESERVOIR MODEL STUDIES — Ballroom, Gunter Hotel

411-G: *The Encroachment of Injected Fluids beyond Normal Well Patterns,* by B. H. CAUDLE, R. A. ERICKSON, and R. L. SLOBOD, The Atlantic Refining Co.

412-G: *Performance of Water Drive Reservoirs, Including Pressure Maintenance, as Determined by the Reservoir Analyzer,* by JAMES M. MCDOWELL, Gulf Research and Development Co.

413-G: *Oil Recovery Performance of Pattern Gas or Water Injection Operations from Model Tests,* by F. F. CRAIG, JR., T. M. GEFFEN, and R. A. MORSE, Stanolind Oil and Gas Co.

9:00 a.m. to 11:15 a.m. — ECONOMICS AND MANAGEMENT — Aztec Theater

420-G: *The Economics of the International Petroleum Industry,* by A. H. CHAPMAN and JAMES TERRY DUCE, Arabian-American Oil Co.

421-G: *Legal Aspects of Offshore Oil Operations,* by Comdr. EMORY CLARK SMITH, Naval Petroleum Reserves.

422-G: *Impact of Federal Regulation of Natural Gas Producers on Future Petroleum Supply,* by J. ED WARREN, National City Bank of New York.

9:00 a.m. to 11:30 a.m. — PRODUCTION OPERATIONS — Roof Garden, Plaza Hotel

384-G: *Studies of the Mechanism of Paraffin Deposition and Its Control,* by D. A. SHOCK, J. J. CROCKETT, and J. D. SUDBURY, Continental Oil Co.

385-G: *Big Mineral Field Exploitation — A Challenge to Engineers,* by J. M. GARLICK, Shell Oil Co.

386-G: *A Low Cost Method of Production Stimulation,* by A. W. GARST, Stanolind Oil and Gas Co.

12:00 m. — PETROLEUM BRANCH MEMBERSHIP LUNCHEON — Ballroom, Gunter Hotel, John R. McMillan, Petroleum Branch Chairman, Presiding

12:00 m. — For the Ladies — LUNCHEON and STYLE SHOW — Menger Hotel

2:45 p.m. to 5:00 p.m. — RESERVOIR MODEL STUDIES — Ballroom, Gunter Hotel

414-G: *Estimated Effect of Horizontal Fractures on Production Capacity,* by PAUL B. CRAWFORD and BOBBY L. LANDRUM, Texas Petroleum Research Committee.

415-G: *Scaling Laws for Use in Design and Operation of Water-Oil Flow Models,* by L. A. RAPOPORT, Carter Oil Co.

416-G: *Displacement of Oil from Porous Media by Miscible Liquids,* by J. OFFERINGA and C. CAN DER POEL, Koninklijke/Shell Laboratorium, Amsterdam.

2:45 p.m. to 5:00 p.m. — PRODUCTION EQUIPMENT Roof Garden, Plaza Hotel

394-G: *Producing Lease Operations — Design of Operating and Maintenance Jobs and Related Tools and Transportation Equipment,* by HAROLD S. KELLY and ROGERS FILSON, Phillips Petroleum Co.

395-G: *Radio Communications in the Petroleum Industry,* by JERRY S. STOVER, Communications Engineering Co.

396-G: *Theoretical and Practical Aspects of Free Piston Operation,* by J. M. LEBEAUX and L. F. SUDDUTH, Stanolind Oil and Gas Co.

397-G: *A New Tool for Perforating Casing Below Tubing,* by B. M. CALDWELL and H. D. OWEN, Welex Jet Services, Inc.

7:00 p.m. to 12:00 m. — PETROLEUM BRANCH BANQUET AND DANCE — Club Seven Oaks, North San Antonio

Wednesday, October 20

8:00 a.m. to 5:00 p.m. — REGISTRATION and EXHIBITS — Ballroom, Plaza Hotel

8:30 a.m. to 11:15 a.m. — FORMATION FRACTURING — Aztec Theater

404-G: *Optimum Sand Concentrations in Well-Treatments,* by PETER DEHLINGER, A&M College of Texas, W. H. BROWNE, Battelle Memorial Institute, and C. O. BUNDRANT, The Western Co.

405-G: *The Development and Application of "Frac" Treatments in the Permian Basin,* by J. M. MOORE, D. E. RAMSEY, and R. E. HURST, Dowell, Inc.

406-G: *Fracturing at High Injection Rates Spraberry Trend Area Field,* by T. P. BROOKS, P. C. O'QUINN, and W. E. LIFE, Southern Production Co., Inc.

407-G: *Effects of Extensive Well Fracturing on the Water Flood Operation in North Texas Strawn Sand,* by GENE E. ROARK and J. D. LINDNER, James A. Lewis Engineering, Inc.

9:00 a.m. to 12:00 m. — DRILLING and WELL COMPLETION — Ballroom, Gunter Hotel

387-G: *Tubing Joints for High-Pressure Service,* by MARTIN E. TRUE and W. M. O'REILLY, Humble Oil and Refining Co.

388-G: *Field Welding on Oil Field Tubular Goods,* by J. N. BIRON and B. G. FRAZIER, Gulf Oil Corp.

389-G: *A Proven Method for the Control of Incompetent Sand Formations,* by H. B. RITCH, Dowell, Inc.

390-G: *Strength of Oil Well Cements and Additives Under High Temperature Well Conditions,* by CALVIN D. SAUNDERS and WAYNE A. WALKER, Halliburton Oil Well Cementing Co.

9:00 a.m. to 11:15 a.m. — GEOLOGICAL ENGINEERING — Roof Garden, Plaza Hotel

398-G: *Application of Radioisotopes to Sub-Surface Surveys,* by A. A. ALBERTS, R. D. COCANOWER, and C. O. BUNDRANT, The Western Co.

399-G: *Use of Spectrographic Analysis for Correlation in Limestone Rocks,* by JOHN C. MILLER and FRANK W. JESSEN, The University of Texas.

424-G: *Radioactive Tracers in Oil Production Problems,* by A. H. FLAGG, E. S. MARDOCK, J. P. MYERS, J. L. P. CAMPBELL, and J. M. TERRY, Lane-Wells Co.

1:30 p.m. to 4:30 p.m. — DRILLING — Ballroom, Gunter Hotel

392-G: *The Pumpability of Clay-Water Drilling Fluids,* by I. HAVENAAR, Koninklijke/Shell Laboratorium, Amsterdam.

393-G: *Lignosulfonate Stabilized Emulsions in Oil Well Drilling Fluids,* by W. C. BROWNING, Marathon Corp.

2:00 p.m. to 4:00 p.m. — RESERVOIR ENGINEERING — Roof Garden, Plaza Hotel

417-G: *Production of Water-Driven Reservoirs Below Their Bubble Point,* by A. B. DYES, The Atlantic Refining Co.

418-G: *Advantage of a Coordinated Formation Evaluation Program,* by H. M. SHEARIN, JR. and J. R. LATIMER, Humble Oil and Refining Co.

★★★

Life Is Different in Historic San Antonio, Site of Fall Meeting

This scene at Club Sevenoaks will be duplicated at the Branch Banquet and Dance on Tuesday evening, October 19.

Contrasting to San Antonio's old world charm, the progressive city is the third largest in Texas, with a population of 455,000. A popular tourist and convention city, it has many attractions of interest to visitors.

The Alamo, La Villita, the numerous Spanish missions, the Spanish Governor's Palace, Brackenridge Park, the Chinese Sunken Garden, and the San Antonio River, wandering peacefully through the heart of the city, are among the points of interest.

The city's cosmopolitan population includes peoples of more than 30 nationalities. The intermingling cultures of the Spanish, the French, the Mexican, the Italian, the German, and the Anglo-American have favorably affected the cultural and economic life of San Antonio. Latin music, symphony orchestras, military bands, jazz bands, art galleries, literary centers, and theaters are all readily available. Skyscrapers which house offices of companies dealing in oil, livestock, banking, and manufacturing link the present with the past.

Tours of Breckenridge Park, the San Antonio missions, and boat rides on the picturesque river are available from the downtown hotels. There are always plenty of things to see and do in the unusual city.

The site of an old Spanish stronghold, it is now the location of probably the largest military concentration in the United States. Surrounding the city are Fort Sam Houston, Lackland, Kelly, Brooks, and Randolph Air Force Bases, and many lesser military installations. Over San Antonio have flown six flags — those of Spain, France, Mexico, the Republic of Texas, the Confederate States of America, and the U. S. A.

Many fine hotels are situated in downtown San Antonio to accommodate Fall Meeting visitors in comfortable and conveniently located rooms. An important place of entertainment will be Club Sevenoaks, the site of the Petroleum Branch Banquet and Dance. This modern country club, on the Austin highway, has spacious facilities for indoor and outdoor dancing and excellent food.

In 1949, 914 men and 200 ladies attended the Meeting which many remember as one of the best Fall Meetings the Branch has had. This year, 2,300 men and 500 ladies are expected; so if the old adage of "the more the merrier" holds true, everyone planning to attend may anticipate four enjoyable and memorable days. ★★★

On a bend in the San Antonio River is located Arneson River Theatre, another tourist attraction in colorful San Antonio.

Ladies' Activities Highlight 1954 Fall Meeting

Historic, romantic, gay San Antonio is the inviting site for the Fall Meeting of the Petroleum Branch, AIME, October 17-20. Ladies' activities will highlight the 1954 meeting more than ever before, an event brought about by the increasing attendance of the ladies in the past four years.

The wives of the Petroleum Branch members have always been welcome at Branch Meetings, but only in the last few years have they attended in such large numbers. In 1950, at the New Orleans Fall Meeting, some 150 ladies attended; Oklahoma City in 1951 drew about 200; and in 1952 Houston played host to 287 ladies during the three-day meeting. Petroleum Branch wives set an all-time high for the Dallas meeting in 1953 when an impressive 400 attended. This year, arrangements are being made for about 500 ladies, and the plans include joint social functions, and informative entertainment as well as socials for ladies only.

This increase in ladies' attendance shows perhaps an increasing amount of interest in the work and activities of their husbands as members of the Petroleum Branch. To this interest and enthusiasm is returned the interest of the Petroleum Branch in the ladies' activities, and the Branch is working to provide the best of entertainment for those ladies who are able to attend.

Social Activities

Mrs. R. K. Guthrie, general chairman of ladies' activities, and her associates have done a wonderful job in planning a Welcoming Merienda, a Luncheon and Style Show, the presentation of the story of petroleum engineering, as well as a hospitality suite at the hotel. Several committees have worked hard to give the ladies tops in entertainment while the husbands are busy with the technical side of the meeting.

The Welcoming Merienda will be in Memorial Hall and the North Patio of the Witte Museum, Brackenridge Park, Monday, October 18, at 10:30 a.m. A Latin-American theme will be carried out with colorful Mexican decorations and roving troubadors. Hostesses in Mexican costumes will guide ladies through points of interest such as the Doll House, Fiesta Wing, and the Pioneer Wing of the museum. The tour will be topped off with coffee and Mexican candies. Humble Oil & Refining Co. will present the favors. Transportation for the museum will leave from the Plaza Hotel.

For the Barbecue Supper and Frontier Party to be held at MacArthur Park, Monday evening, October 18, colorful print blouses and cotton skirts will be the proper costume for the ladies and blue jeans will be the attire for the men. This gala affair will feature good food, comfortable backyard atmosphere, and dancing on an open pavillion.

Luncheon and Style Show

The luncheon and style show will be in the Colonial and Minuet Rooms of the Menger Hotel Tuesday, October 19, 12:30 p.m. The style show will be presented through the courtesy of Joske's of Texas, a leading women's apparel department store in San Antonio. Featuring ensembles for every occasion, winter and holiday styles will be shown by such designers as Christian Dior, Maurice Rentner, Larry Aldrich, Adele Simpson, and Monte Sano. Millinery creations of Mr. John, Hattie Carnegie, Christian Dior, and John Frederics will also be shown by professional models. Individual corsages will be presented to the ladies by Merla Tool Corp.

The formal event of the meeting will be the Petroleum Branch Banquet and Dance Tuesday night, October 19, at Club Sevenoaks. The Club has recently changed from a night club to a country club and the facilities are of the finest (see the photograph of the band shell and dance floor on page 32.) For this evening in romantic San Antonio a dinner dress — either short or long will be in order. If packing space won't pemit — a cocktail dress may be worn.

Wednesday at 10 a.m., Joe B. Alford, executive secretary of the Petroleum Branch, will narrate a photographic slide presentation of the story of petroleum engineering. The location of the presentation of "How Petroleum Engineering Increases Oil Recovery" will be announced later. Ladies and members are cordially invited to take advantage of this informative pictorial story.

Hospitality Suite

The hospitality suite will be in the Gunter Hotel, which is centrally located in the heart of the city. All ladies attending are invited to go by the suite to take advantage of the coffee, conversation, and just plain relaxation. Local members' wives, headed by Mrs. W. W. Hammond, will hostess the suite from Monday at 1 p.m. through Wednesday afternoon. There will be all sorts of information available for places to shop, sightseeing tours (don't miss seeing at least part of the famed San Antonio River), and details of general interest.

Members and their wives who attended the Branch Meeting in San Antonio in 1949 recall it as one of our most enjoyable. The forthcoming one promises to keep up this standard, and the ladies who attend will experience something to remember. ★★★

JAN GARTMAN

Witte Museum, Brackenridge Park, site of the ladies' Welcoming Merienda.

"LONG DISTANCE" PLANNING of FALL MEETING NO OBSTACLE to SOUTHWEST TEXAS SECTION

Paul R. Turnbull
Del Mar Drilling Co.
Welcoming Luncheon

Southwest Texas Local Section Chairman Chester Wheless resides in Corpus Christi — 150 miles from San Antonio, the Fall Meeting site. So do most of the members of his local section. It is a big job to plan and prepare for a major convention under ideal conditions, but the complexity is increased tremendously when the committee chairmen must coordinate their activities via long distance.

Even under these difficult conditions, the Southwest Texas local section members have successfully planned and made detailed arrangements for what promises to be the largest and one of the best fall meetings.

Chester L. Wheless
La Gloria Corp.
Chairman, Southwest Texas Local Section

H. N. Lyle
Renwar Oil Co.
Finance

J. M. Montgomery
Halliburton
Entertainment

Houston Parish
Engr. Serv. Co., Inc.
Registration

J. R. Tower
Seeligson Engr. Com.
Housing

R. K. Guthrie
Seeligson Engr. Com.
Vice-Chairman, Southwest Texas Section

Mrs. R. K. Guthrie
Ladies'
Entertainment

R. E. Warner
Forest Oil Corp.
Arrangements

WORK of BRANCH TECHNOLOGY COMMITTEE PRODUCES 'SOMETHING for EVERYBODY'

W. L. Horner

Technical papers are the heart of every Fall Meeting, notwithstanding the fact that the reunion of old friends, the social activities, and the business transacted are also important. The job of seeking out the best papers available for presentation at the technical session falls to the Technology Committee.

Six Committee Members, each having charge of a specific field of interest, have aided Chairman William L. Horner, Core Laboratories, Inc., in preparing for this year one of the most well-rounded programs ever presented. "A little something for everybody" is included in the 1954 program which contains more papers than ever before.

W. W. Hammond

P. E. Chaney

The Committee members who compiled the papers are: Preston E. Chaney, drilling, Sun Oil Co., Beaumont; W. W. Hammond, geological engineering, Ralph E. Fair, Inc., San Antonio; William H. Speaker, natural gas engineering, Magnolia Petroleum Co., Dallas; John H. Thacher, petroleum economics, California Research Corp., San Francisco; Lewis Finch, Jr., production engineering, Stanolind Oil & Gas Co., Tulsa; and L. P. Whorton, reservoir engineering, The Atlantic Refining Co., Dallas.

This year the Committee members studied over 80 papers in selecting the 46 to be presented at the Meeting. Their work began early last spring and continued through the summer months.

W. H. Speaker

J. H. Thacher

The first step in their important job was to plan a well-rounded program based on a recent study of the technical interests of Petroleum Branch members. The number of papers in each field to be presented was determined on the basis of this study.

Then, they began to seek out appropriate papers. Each vice-chairman of the Technology Committee contacted representatives of various companies and asked them to provide descriptions of papers that would be available for the meeting.

Next, as the paper descriptions were received, each vice-chairman rated them according to their importance in their particular field. Because only brief descriptions were available of most papers, some excellent presentations may have been overlooked — but the Committee worked to keep such oversights to a minimum.

At the final meeting of the Committee the members compared their written opinions of the papers and carefully weaved those rated most highly into the framework of the program established earlier.

It would be impossible to estimate how much time was spent in establishing the general plan of the program, soliciting the papers, studying and evaluating the descriptions, and fitting the selected papers into the framework of this program.

Lewis Finch, Jr.

L. P. Whorton

The importance of the work of this Committee goes far beyond the Fall Meeting. The publications program of the Branch is greatly dependent upon the papers chosen at this time and made available for future publication in the JOURNAL OF PETROLEUM TECHNOLOGY and the Petroleum Transactions volume.

The increased size of the program this year made the job of this year's Committee probably the largest yet handled. The Petroleum Branch is sincerely appreciative of the work done by the 1954 Technology Committee. Upon reading the program which is printed on pages 30 and 31 of this issue, undoubtedly each member will agree that the Committee has done an excellent job. ★★★

ABSTRACTS of TECHNICAL PAPERS TO BE PRESENTED at BRANCH FALL MEETING

365-G

The Phase and Volumetric Behavior of Natural Gases at Low Temperatures and High Pressures

P. C. Davis, A. F. Bertuzzi, T. L. Grove and Fred Kurata, *University of Kansas*

The phase and volumetric properties of 10 very volatile mixtures are presented for temperatures from — 200°F to above the critical points. These mixtures consisted of natural gases and correlations of mixtures of natural gases with methane and nitrogen. Methods have been developed for estimating critical temperatures of these mixtures to ± 4°F and critical pressures to ± 5 per cent. These methods apply to other volatile and very volatile mixtures. The results of this work are particularly applicable to the separation of nitrogen from hydrocarbons by low-temperature distillation.

379-G

A Study of the West Cement Medrano Unit — Caddo County, Oklahoma

Alvin E. Hall, *Phillips Petroleum Co.*

Included in this paper is essential data on reservoir characteristics, history of development, and reservoir performance of a field under both competitive and unitized gas injection operations. Before the field was unitized in 1947, it produced from a gas cap above an oil reservoir for six years before oil was discovered and then for four and one-half years as a combination pool with both gas and oil wells producing on a competitive basis.

380-G

Pressure Maintenance by Inert Gas Injection in the High Relief Elk Basin Field

F. M. Stewart, D. L. Garthwaite, and F. K. Krebill *Stanolind Oil & Gas Co.*

Pressure has been maintained in the Elk Basin Tensleep reservoir since the initiation of inert gas injection in September, 1949. Oil is being produced under conditions favorable for gravity drainage, including high angle of dip, appreciable structural closure, and fairly good permeability. Results being obtained are high per cent recovery of oil-in-place, sustained field productivity, reduced operating problems, and recovery of plant products. The high recovery has been calculated by application of the gravity drainage theory and confirmed from field performance by comparing oil recovery to date with gas cap space voided. This paper discusses the production history, rock and fluid characteristics, and oil recovery efficiency of this reservoir.

381-G

External Casing Corrosion Control

J. D. Sudbury, J. E. Landers, and D. A. Shock *Continental Oil Co.*

The external corrosion of casing is one of the most important problems facing the present-day production man. Data were presented recently by the NACE indicating the extreme number of failures due to external corrosion. This paper presents a discussion of an instrument designed for studying external electrolytic corrosion. The use of the instrument to determine the quantity of protective current required to prevent corrosion of casing is explained. Also, the problem of accelerated external corrosion of the oil string at the base of the surface string is treated.

382-G

Remote Automatic Control of Oil Production

C. R. Bayless and Joe W. Daughtrey, *Gulf Oil Corp.*

The era is approaching when electronic equipment similar to that used by many pipeline companies for the remote control and supervision of pipeline stations may be applied to the production phase of the oil industry. The basic circuits are now being field tested by the Gulf Refining Co. in Timbalier Bay, La.

383-G

Where Corrosion Control Stands Today

H. L. Bilhartz, *Production Profit, Inc.*

This paper describes briefly the current status of corrosion in the oil and gas industry. Specifically, the paper deals briefly with the history of development of corrosion techniques, classification of various types of corrosion, criterion for determining corrosion, remedial measures employed, and a discussion of future action to combat the corrosion problem.

384-G

Studies of the Mechanism of Paraffin Deposition and its Control

D. A. Shock, J. J. Crockett, and J. D. Sudbury *Continental Oil Co.*

This paper attempts to better define the causes of oil field paraffin deposition and possible methods for its alleviation. In order to achieve a broad picture of this problem, studies of crude oils and paraffins over a wide range of production are included. Some of the major factors believed to influence the rate of paraffin deposition are discussed and the laboratory techniques for studying these factors are explained. Evaluations of current and possible future methods for the mitigation or inhibition of paraffin deposition are discussed.

385-G

Big Mineral Field Exploitation — A Challenge to Engineers

J. M. Garlick, *Shell Oil Co.*

Exploitation of the Big Mineral field, located in north central Texas, has been and continues to be a challenge to the engineer. The field is partially inundated by the waters of Lake Texoma. Multi-zone oil production ranging from 3,600 to 10,200 ft is found in steeply dipping Pennsylvanian and Ordovician sediments. This paper brings into sharp focus the contributions of each branch of engineering to the solution of the major development and production problems.

386-G

A Low Cost Method of Production Stimulation

W. A. Garst, *Stanolind Oil and Gas Co.*

A simple treatment has been developed by which water-block is removed from oil wells by lowering oil-water interfacial tension to a very low value. The treatment is made by injecting a crude-oil solution of a carefully selected surface active agent into the water-blocked formation. From 1,000 to 4,000 gals. of crude oil containing 1 per cent surface active agent is used. The treatment has been used in 90 wells with successful results obtained in 39 wells representing seven formations in nine fields.

387-G

Tubing Joints for High-Pressure Service

Martin E. True and W. M. O'Reilly, *Humble Oil & Refining Co.*

Samples of tubing joints, considered as an item of well equipment very susceptible to leakage in high-pressure gas service, were subjected to a series of tests involving thermal changes and using gas at pressures to 15,000 psi. It appears that some joints commercially available and of special design give promise of adequately containing 15,000 psi gas pressure under field conditions. Observations indicate that physical turns as a measurement are superior to torque as an index of make-up and relative sealing ability of a joint.

388-G

Field Welding on Oilfield Tubular Goods

J. N. Biron and B. G. Frazier, *Gulf Oil Corp.*

Examination of several typical samples of field welding of scratcher and centralizer lugs revealed that the quality of welds was inconsistent and generally poor. Damage to the casing could usually be expected. A non-technical summary of the effects of welding on metals, particularly oilfield tubular goods, is presented. A study of this will give an appreciation of the problem of joining metals by arc welding. Five categories of welding at the rig site are considered.

389-G

A Proven Method for the Control of Incompetent Sand Formations

H. B. Ritch, *Dowell, Incorporated*

A sand control process has been developed and field proven in the Gulf Coast. The mechanics of the application involve the use of a gel oil (or gel acid or gel water) as a vehicle to carry sand into or against the formation which has or is expected to produce sand. This process, carried out beneath a squeeze tool, makes it possible to pack a formation without mud or water contamination. After successful packing, a screen liner or sand consolidation plastic is used. Work which has been done to determine the most effective packing sand and gravels has been analyzed and tabulated.

390-G

Strength of Oil Well Cements and Additives Under High Temperature Well Conditions

Calvin D. Saunders and Wayne A. Walker
Halliburton Oil Well Cementing Co.

Recent tests have shown that the strengths of cement will decrease with increase in temperature and age above a critical temperature. The critical temperature appeared to be approximately 220 to 240°F. This paper presents results of tests which were designed to determine, if possible, the cause and means of overcoming this strength loss. No definite conclusions are drawn at this time, but it appears that by the proper selection of additives for cement, strength loss with age at high temperature can be either eliminated or considerably lessened.

392-G

The Pumpability of Clay-Water Drilling Fluids

I. Havenaar, *Koninklijke/Shell-Laboratorium, Amsterdam*

Data are presented showing the validity of proposals in the literature on methods to calculate the pressure losses in drill-pipe and bit-nozzles, those parts of the mud-circuit where the largest pressure-losses occur. The results of pumping experiments with clay-water drilling fluids of different specific gravities and different laminar flow-properties (differential viscosity and Bingham yield value) using pipes of different diameters are presented. In addition, a series of measurements on bit-nozzles is discussed.

393-G

Lignosulfonate Stabilized Emulsions in Oil Well Drilling Fluids

W. C. Browning, *Marathon Corp.*

Oil-in-water emulsions have become important in oil well drilling fluids. Lignosulfonates, prominent among various stabilizing agents, have been used successfully in Texas for several years in both lime-base and brine-base fluids. This paper is concerned with the surface active properties of the lignosulfonates, the characteristics of lignosulfonate stabilized emulsions, and their application to oil well drilling. A more complete understanding of lignosulfonates and their potentialities may aid in the development of drilling fluids designed to cope with certain of the many problems encountered in oil well drilling.

394-G

Producing Lease Operations — Design of Operating and Maintenance Jobs and Related Tools and Transportation Equipment

Harold S. Kelly and Rogers C. Filson,
Phillips Petroleum Co.

The paper reviews some of the economics achieved through methods work on lease producing operations and depicts some of the tools and special transportation units that were designed and put into service to improve the efficiency of the working force, lengthen the life of the lease equipment, and reduce downtime lost production. It covers three broad categories of work as they were delineated by the methods studies: namely, operations, tune-up and preventive maintenance, and field maintenance and repair.

395-G

Radio Communications in the Petroleum Industry

Jerry S. Stover, *Communication Engineering Co.*

The purpose of this paper is to provide the petroleum engineer with a general description of the various types of petroleum radio systems, capabilities, limitations, cost and operating features. Petroleum engineers may frequently be called upon to consult with the radio engineer in the design of a system for an oil company's particular operation, and with a working knowledge of radio along with a detailed knowledge of his company's operation, he can be of material assistance in the equipment design.

396-G

Theoretical and Practical Aspects of Free Piston Operation

J. M. Lebeaux and L. F. Sudduth
Stanolind Oil & Gas Co.

Theory of operation of the free piston as well as practical limits of the device in prolonging flowing life of wells producing from volumetric type reservoirs are discussed. Reservoir behavior and the gas expansion work formulae are used to exhibit utility of the free piston in prolonging natural flowing life. Examples are exhibited to show actual performance of the tool in West Texas. Investment and operating costs of the free piston are compared with those required for other artificial lift methods. A nomograph which may be used in determining adaptability of the tool is exhibited.

397-G

A New Tool for Perforating Casing Below Tubing

B. M. Caldwell and H. D. Owen
Welex Jet Services, Inc.

A new shaped charge thru-tubing perforator has been developed in which the charges are run through the tubing in a vertical position and then opened out to a horizontal position when at the shooting zone. The tool was designed to be used in the permanent well completion technique. The paper describes the new tool and its applications. Performance data in targets and under various actual well conditions are presented.

398-G

Application of Radioisotopes to Sub-Surface Surveys

A. A. Alberts, R. D. Cocanower, and C. O. Bundrant,
The Western Co.

Recent advances in the technology of the use of radioisotopes has enabled the development of new techniques for oil and gas well surveys. Almost without limit, these surveys can be designed to answer questions regarding down-the-hole well conditions. They have been found to be reliable and relatively inexpensive. This paper describes a few of the many possible applications of the plating-out technique, or filter-cake buildup of the radiotracer on the formation, in an effort to illustrate the potentiality of the new tool.

399-G

An Investigation of the Use of the Spectrograph for Correlation in Limestone Rock

F. W. Jessen and John C. Miller, *University of Texas*

Equipment is now available commercially with which very rapid spectrographic analyses may be made, and hence the purpose of this study was to determine whether the variations existing in the minor constituents of limestones were sufficient for use in possible correlation. Qualitative and semi-qualitative investigations were made to determine whether significant changes in the chemical compositions occurred. It was a further purpose to investigate the geologic time-boundaries to see whether significant chemical variation could be found corresponding to the paleontological breaks.

400-G

A Subsurface Flowmeter

R. C. Rumble, *Humble Oil & Refining Co.*

A self-contained instrument which can be lowered on a wire line through tubing to measure accurately fluid flow in wellbores is described. By this technique, it is possible to determine points of entry of fluids from the formation and casing leaks by subsurface measurements. The instrument has several unique features which may prove to be adaptable to other purposes which are discussed.

401-G

A Method for Neutron-Derived Porosity for Thin Beds

J. M. Edwards and A. L. Simpson, *McCullough Tool Co.*

The application of the Scintillometer has made it possible to accurately determine bed thickness. This fact, combined with known relation of logging variables, makes thin bed porosity determination practical. With the use of the Scintillometer a method has been derived whereby the apparent level of radioactivity, as recorded on radiation logs, may be converted to the true level. A thorough discussion of the concept of time constant, drag, and logging speed is undertaken, as is the spacing effect on the neutron curve.

402-G

A Study of Electric Log Interpretation Methods in Shaly Formations

Leendert de Witte, *Continental Oil Co.*

To date various theories have been presented on the self-potential and the conductivity of shaly sands, based on the concepts of electrochemical behavior in ion exchange membranes. In general, the relations given are variations of the Meyer Sievers equation and have been applied mainly to water sands. This paper presents a new set of electrochemical derivations based on the concept of strongly-reduced activity of the double layer counter ions near the negatively-charged rock surfaces. The equations are extended to the case of oil bearing formations and are compared with previously established relations based on physical models of electrical behavior in shaly sands and on empirical data. Results of laboratory measurement are presented in support of the theoretical work and a field example of log interpretation in a shaly oil sand is given.

404-G

Optimum Sand Concentrations in Well Treatments

Peter Dehlinger, *A&M College of Texas*

W. H. Browne, *Battelle Memorial Institute*, and

C. O. Bundrant, *The Western Co.*

Laboratory investigations to determine optimum sand concentrations in gel-sand and oil-sand well treatments are described. The investigations apply to the case where sand acts as a propping agent in formation fractures. Both analytically and experimentally it is demonstrated that optimum sand concentrations can be defined, but the difficulty in translating laboratory results to field treatments is explained. It is also demonstrated that to inject sand into fractures, the fracture width must be at least that of the sand grain diameter.

405-G

The Development and Application of "Frac" Treatments in the Permian Basin

J. M. Moore, D. E. Ramsey, and R. E. Hurst

Dowell, Inc.

A brief history of the use of the fracturing treatments in the Permian Basin is given. A discussion is given of the different treating techniques and "fracturing fluids" developed in order to obtain maximum stimulation benefits in the different well conditions encountered, such as rock solubility, initial permeability, and bottom hole temperature and pressure. Other important considerations in planning a fracturing treatment which are discussed are the sand concentration injection rates and the size of the treatment.

406-G

Fracturing at High Injection Rates — Spraberry Trend Area Field

Thomas P. Brooks, Percy C. O'Quinn, and

Warner E. Life, *Southern Production Co., Inc.*

The application of large volume fracture treatments with an oil sand mixture at high injection rates in wells completed in the Spraberry formation has indicated improved drainage from the matrix rock. This is considered to result from enlargement of existing open fractures, possibly from opening of fractures not previously effective, and breaking down existing blockage in the vicinity of the wellbore. The results of this type of treatment as applied to a group of wells in the Spraberry Trend Area field is discussed with reference to well performance and economics.

407-G

Effects of Extensive Well Fracturing on the Water-Flood Operation in North Texas Strawn Sand

Gene E. Roark and J. D. Lindner

James A. Lewis Engineering, Inc.

This paper describes water-flood operations in progress in the Langston-Kleiner field, Young County, Tex., in which most of the injection and producing wells were hydraulically-fractured prior to water flooding. The water flood in progress, the nature of the fracturing operations, and the performance characteristics which are being observed after 18 months of water-flood operations are described. It is pointed out that the fracturing treatments in the well have improved both injection and production characteristics and have not been detrimental with respect to affecting the advance of the flood fronts.

408-G

Differences in Behavior of Fresh and Aged East Texas Woodbine Cores

J. G. Richardson, F. M. Perkins, J. S. Osoba,

Humble Oil & Refining Co.

Laboratory experiments have shown profound differences in the behavior of so-called "fresh cores" from the East Texas field and of the same cores after extraction with organic solvents. The residual oil saturation remaining after water flooding fresh cores was appreciably lower. This behavior was also reflected in the water-oil relative permeability-saturation relations. Residual water saturation after displacement of water by oil was higher in the fresh cores than in the extracted cores. Capillary pressure-saturation relations were also different. Imbibition experiments indicated that the rate of imbibition of water was higher for samples after extraction than it was for fresh core material.

409-G

A Study of Water-Flood Efficiency in Oil-Wet Systems

J. E. Warren and John C. Calhoun, Jr.

Pennsylvania State University

A study of water-flood efficiency, given in terms of oil recovery at water breakthrough and ultimate recovery, has been made on short, consolidated Pyrex glass cores rendered oil-wet by chemical treatment. The data permit interfacial tension, contact angle, porosity, and permeability to be grouped into a scaling coefficient along with viscosity, velocity of flooding and length of core. The work indicates that with proper control a group of similar natural cores of permeability plug size can be correlated to indicate basic flooding performance.

410-G

The Role of Bubble Formation in Oil Recovery by Solution Gas Drives in Limestones

C. R. Stewart, E. B. Hunt, Jr., F. N. Schneider, T. M. Geffen, and V. J. Berry, Jr., *Stanolind Oil & Gas Co.*

An experimental study is made of the differences in performance of non-uniform porosity limestones under solution gas drive. In the laboratory the gas-oil relative permeability ratio performance of this type of rock is sensitive to producing rate and fluid characteristics. The laboratory tests sometimes indicate oil recoveries from solution gas drive up to twice those expected from the field. These differences in recovery are due to the formation of greater number of bubbles in the tests than are formed under field operating conditions. Laboratory test data is evaluated in regard to its use for the prediction of reservoir performance in non-uniform porosity limestones.

411-G

The Encroachment of Injected Fluids Beyond the Normal Well Pattern

B. H. Caudle, R. A. Erickson, and R. L. Slobod, *The Atlantic Refining Co.*

This paper presents the results of a laboratory study in which the area contacted around the edge of a reservoir injected in a five-spot pattern was determined. The X-ray shadowgraph technique was used in this study. Surprisingly large portions of the reservoir area lying outside the well network are contacted by the injected fluid before abandonment conditions are reached. From this paper, it is possible to estimate not only the extent to which encroachment into these areas will occur, but also the injection volume necessary to produce the wells to abandonment conditions.

412-G

Performance of Water Drive Reservoirs, Including Pressure Maintenance, as Determined by the Reservoir Analyzer

James M. McDowell, *Gulf Research & Development Co.*

A study has been made to determine how the behavior of a water drive reservoir would change as a function of the permeability of the formation, and as a function of the size of the aquifer. The effect of pressure maintenance programs on the rate of natural water influx is also studied, as well as the influence on the influx of the position of water injection wells with reference to the oil-water contact. The results are determined by the use of an electrical reservoir analyzer and are plotted as families of curves of pressure, natural water influx, and water injection versus time or cumulative production. Two size aquifers are studied.

413-G

Oil Recovery Performance of Pattern Gas or Water Injection Operations from Model Tests

F. F. Craig, Jr., T. M. Geffen, and R. A. Morse, *Stanolind Oil & Gas Co.*

Tests were conducted on consolidated sandstone models using oil, water, and gas to reproduce field performance under gas and water five-spot injection. X-ray shadowgraphs were used. Methods were developed for applying the mobility ratio concept to water-flooding and dispersed gas drives in a five-spot well pattern and for predicting the water-oil ratio performance of five-spot pattern water floods in uniform sands. A study was made to determine how oil recoveries from a pilot flood can be used to evaluate oil recoveries from field-wide flooding.

414-G

Estimated Effect of Horizontal Fractures on Production Capacity

Paul B. Crawford and Bobby L. Landrum, *Texas Petroleum Research Committee*

An electrical model study has been made of the effect of horizontal fractures on the production capacity of fractured wells. For thin reservoirs increases in production capacity by factors of 4 to 12 may be obtained if the radius of the fracture is between 0.2 and 0.6 the drainage radius. For thick reservoirs the increases in production capacity depends on whether the fracture is located at the top, bottom, or center of the pay. Inclined circular fractures are indicated to be slightly less effective than horizontal fractures of the same radius. Elliptical and circular horizontal fractures with the same radius produce equally.

415-G

Scaling Laws for Use in Design and Operation of Water-Oil Flow Models

L. A. Rapoport, *The Carter Oil Co.*

The mathematical formulation of incompressible, two-phase flow phenomena in a three-dimensional porous medium is presented. The resulting equations which account for the effects of gravitational and capillary forces are used to derive general scaling laws permitting accurate representation of water-oil displacement processes by means of experimental flow models. The significance of the scaling laws is examined in the light of the physical concepts of micro-behavior of fluids in porous media. Formulations of scaling conditions obtained by application of dimensional analysis are reviewed. The principles of application and the limitations of flow model studies are discussed.

416-G

Displacement of Oil from Porous Media by Miscible Liquids

J. Offeringa and C. van der Poel, *Koninklijke/Shell-Laboratorium, Amsterdam*

Scaled model experiments on the recovery of oil from porous sands by the injection of miscible liquids (solvents) and the subsequent recovery of the solvents by water flooding are described. Scaling rules are deduced and their correctness is checked by carrying out experiments in tubes of various sizes. Data are submitted on the effect of the viscosity ratio oil-solvent on the efficiency of the displacement process. The results of scaled experiments are compared with those of other investigators. A circulation process is introduced.

417-G

Production of Water-Driven Reservoirs Below their Bubble Point

A. B. Dyes, *The Atlantic Refining Co.*

In the operation of a water-driven reservoir, a free gas saturation can be established by maintaining production rates fast enough to cause the reservoir pressure to decline below the bubble point. The benefit of such a procedure on the displacement efficiency of the oil by water is illustrated for two types of sandstone samples from one reservoir. Displacement of oil at the optimum pressures results in the removal of 7 to 12 per cent more oil than would be obtained by displacement at the bubble point pressure. In some instances this magnitude of increase may be worthy of consideration in establishing the maximum efficient rate of production from many water-driven fields.

418-G

Advantages of a Coordinated Formation Evaluation Program

H. M. Shearin, Jr., and J. R. Latimer, *Humble Oil and Refining Co.*

This paper points out the desirability of determining the merits of various formation evaluation systems in order that a program can be adopted that will give the maximum information at a minimum cost, keeping in mind some of the more important usages of this information in recent years for such purposes as reservoir studies and unitization. Specific illustrations are included to show how formation evaluation may be organized for a particular field. This illustration briefly shows some of the more recent usages of radioactivity logging.

420-G

The Economics of the International Petroleum Industry

A. H. Chapman and James Terry Duce, *Arabian-American Oil Co.*

This paper presents a history of the world's use of energy and, in some areas, attempts to evaluate trends of energy consumption, particularly in the United States and Europe. The question of how this demand will be met is discussed, with particular emphasis on trends in the United States and the Middle East. An economic comparison between the development of productive sources in the United States and in the Middle East examines economic and political difficulties which are encountered in the latter area.

421-G

Legal Aspects of Offshore Oil Operations

Emory Clark Smith, *Commander, U. S. Navy*

The Outer Continental Shelf Land Act and the Submerged Lands Act are discussed. More important, the Leasing and Operating Regulations for the Submerged Lands of the Outer Continental Shelf are analyzed in some detail. Geological considerations are used to propound the theory that it is preferable to place the boundary at the outer margin of the continental shelf. The influence of international law with respect to offshore oil operations is treated.

422-G

Impact of Federal Regulation of Natural Gas Producers on Future Petroleum Supply

J. Ed Warren, *National City Bank of New York*

The Supreme Court decision rendered June 7, 1954, defined natural gas producers who sell gas for resale and interstate commerce as natural gas companies under the Natural Gas Act. It is now clearly established that producers and gatherers of natural gas are subject to Federal Power Commission regulations. The only course left open to the producers' dilemma is the enactment of clarifying legislation. The specific issue that initiated the controversy and impact of producers' prices on the price paid by the residential consumer and the general issue concerning the effect of Federal Power Commission price determination at the producers' level upon the petroleum energy supply are both discussed.

423-G

Secondary Recovery Operations in the Tijerina No. 3 Unit Reservoir, Tijerina-Canales-Blucher Field, Jim Wells County, Texas

N. A. Olansen, *The Texas Co.*

This paper presents the production history of Tijerina No. 3 Reservoir from its initial development in April, 1945, through April, 1954, including primary development, unitization, and secondary recovery by high pressure gas injection. Particular attention is given reservoir performance as influenced by the migration of fluids in a continuous but erratic sand of low permeability. It is observed from material balance calculations, that little or none of the injected gas goes into solution with the remaining reservoir oil even though reservoir pressure has been increased an average of 700 psi.

424-G

Radioactive Tracers in Oil Production Problems

A. H. Flagg, E. S. Mardock, J. P. Myers, J. L. P. Campbell, and J. M. Terry, *Lane-Wells Co.*

The development process for the use of radioactive tracers as a means of locating zones of permeability is discussed. The developments in the general techniques for the safe handling of radioactive materials are given. The problems and successes with tracers in waterflood systems, oil and gas injection profiles, fracture sand tracing, squeeze cement tracing, lost circulation, and cement top location are discussed and illustrated.

425-G

Corrosion of Oil Well Casing by Earth Currents

Leendert de Witte and Fred J. Radd, *Continental Oil Co.*

The thesis presented in this paper is that the SP currents which are measured in electric logging are short circuited when casing is set in a drill hole and that their combined effects play a major role in outside casing corrosion. The general nature of the spontaneous Emf's is discussed and equivalent circuits are given. The problem of the Kansas casing corrosion in the vicinity of the Dakota water sands is used as a qualitative illustration. A quantitative analysis based on linear transform theory is presented, and results are compared with casing current surveys.

EXHIBITORS' GUIDE

Exhibitor	Booth
American Iron & Machine Works Co.	16
Atomic Energy of Canada, Ltd.	28
B & W, Inc.	8
Baker Oil Tools, Inc.	10
Brown Oil Tools, Inc.	32
Camco, Inc.	26, 27
Christensen Diamond Products Co.	7
Communications Engineering Co.	25
Core Laboratories, Inc.	12
The Dia-Log Co.	13, 14
Dowell, Inc.	1
Dresser Industries, Inc.	33, 34
Garrett Oil Tools, Inc.	24
Geophysical Research Corp.	31
George E. Failing Co.	30
Halliburton Oil Well Cementing Co.	3
Johnston Testers, Inc.	5, 6
Keystone Development Corp.	35
Kimray, Inc.	15
Lane-Wells Co.	23
McCullough Tool Co.	4
Merla Tool Corp.	17
Oil Center Tool Co.	2
Orbit Valve Co.	9
Otis Pressure Control, Inc.	11
Ozalid Division, General Aniline & Film Corp.	29
Schlumberger Well Surveying Corp.	36
Shaffer Tool Works	18
Visco Products Co., Inc.	19
Welex Jet Services, Inc.	20

Advance Registration

DEADLINE — SEPTEMBER 30

Petroleum Branch

Fall Meeting

OCTOBER 17-20

Send your registration today to avoid the registration lines and to be assured of getting tickets to all activities. Registration forms were sent to all Petroleum Branch members in the United States on September 10. They must be mailed back to the Petroleum Branch office by September 30.

Mail Your Registration Today!

Branch Offers Books at Discount; Display Planned at Fall Meeting

Several books are now available at discount prices through the Petroleum Branch. These books will be displayed in the membership booth at the Fall Meeting in San Antonio on October 17-20 and may be ordered at this booth or by mail, or from the Branch Office.

The membership booth will be located in the lobby of the Plaza Hotel at the head of the stairway on the mezzanine floor. In addition to the books listed below, the new Index to Petroleum Publications of the AIME, the books given to new Junior Members through the Mudd Fund, and other AIME publications will be available for perusal.

	List Price	Price to AIME Members
Physical Principles of Oil Production, by Morris Muskat, McGraw Hill Book Co., 1949, 922 p.	$15.00	$12.00
Principles of Petroleum Geology, by William L. Russell, McGraw Hill Book Co., 1951, 508 p.	7.50	6.00
Fundamentals of Reservoir Engineering, by John C. Calhoun, Jr., University of Oklahoma Press, Revised ed., 1953, 417 p.	6.00	4.80
Petroleum Geology, by Kenneth K. Landes, John Wiley & Sons, 1951, 660 p.	10.00	8.00
Oil Property Valuation, by Paul Paine, John Wiley & Sons, 1942, 204 p.	3.50	2.80
Technical Reporting, by Joseph N. Ulman, Jr., Henry Holt & Co., 1952, 289 p.	4.75	3.80
Marine Geology, by Ph. H. Kuenen, John Wiley & Sons, 1950, 568 p.	8.00	6.40
Hydrocarbons from Petroleum, by Frederick D. Rossini, Beveridge D. Mair, and Anton J. Streiff, Reinhold Publishing Corp., 1953, 556 p.	18.50	14.80
Outlines of Structural Geology, by E. Sherbon Hills, John Wiley & Sons, 3rd ed., revised 1953, 182 p.	3.00	2.40
Volumetric and Phase Behavior of Oil Field Hydrocarbon Systems, by M. B. Standing, Reinhold Publishing Corp., 1952, 123 p.	10.00	8.00
Oil in the Soviet Union, by Heinrich Hassman, translated by Alfred M. Leeston, Princeton University Press, 1953, 173 p.	3.75	3.00

HAVE YOU CHANGED YOUR ADDRESS?

In order that publications and correspondence may reach you promptly, the Petroleum Branch, AIME, should be advised as soon as possible of any change in your address, *preferably a month before the change becomes effective.* For the AIME directory and for the Personals column of the JOURNAL OF PETROLEUM TECHNOLOGY, additional information is desired. The form below is provided for your convenience, and should be sent to Petroleum Branch, AIME, 800 Fidelity Union Bldg., Dallas 1, Tex.

Name_____ Membership No._____

Old Address_____

_____

New Address for Publications_____

Title or Position Held_____

Address for Directory Listing_____

_____

List below your former title or company position, nature of your new position, or other information of interest to your associates for publication in the JOURNAL OF PETROLEUM TECHNOLOGY.

_____

_____

One month normally required for change of address.

FIVE HUNDRED EXPECTED FOR COAST FALL MEETING

Approximately 500 are expected to attend the Pacific Petroleum Chapter Fall Meeting to be held October 7 and 8 at the Los Angeles Biltmore Hotel. Advance registration is being conducted for the benefit of those interested in being assured admittance to all functions.

Each half-day meeting is devoted to covering one technical subject. Formation evaluation is the topic to be discussed at the Thursday morning session, and drainhole drilling is the subject for the afternoon meeting. On Friday, fluid injection will be discussed in the morning session, with management and oil field performance the afternoon topics. A total of 12 papers will be presented during the two-day meeting.

The Southern California Section Luncheon is scheduled for Thursday noon. At noon on Friday, John R. McMillan will speak at the Pacific Petroleum Chapter Luncheon. The informal dinner dance scheduled for Friday evening in the Renaissance Room of the Biltmore will feature the music of Carrol Wax and his orchestra.

Howard C. Pyle, president of Monterey Oil Co., is the general chairman of the meeting, and R. S. Crog is in charge of the technical program.

PACIFIC CHAPTER FALL MEETING EXHIBITORS' GUIDE*

B & W, Inc.
Baker Oil Tools, Inc.
Baroid Sales Division, National Lead Co.
Eastman Oil Well Survey Co.
Ford Alexander Corp.
Formation Logging Service Co.
Halliburton Oil Well Cementing Co.
Hercules Filter Corp.
Johnston Testers, Inc.
Lane-Wells Co.
Macco Corp.
Martin-Decker Corp.
Munger Oil Information Service
McCullough Tool Co.
National Supply Co.
Oil Base, Inc.
Pacific Perforating Co.
Rapid Blue Print Co.
Schlumberger Well Surveying Corp.
Tretolite Co. of California
Weatherford Oil Tool Co.

*This list was complete as of Aug. 24, 1954. Exhibitors contracting for space after this date are not included.

AIME President, Past Presidents, Legion Members Honored at California Meeting

An All-Division Meeting to honor AIME President Leo F. Reinartz was held by the Southern California Section on September 17. Also honored at the dinner were Legion of Honor members and past presidents of the AIME.

The meeting was sponsored by all Branches of the Southern California Section, the Ladies' Auxiliary, and the Open Hearth Steel Committee.

PROGRAM SET for OCTOBER PACIFIC FALL MEETING

Dozen Technical Papers; Many Social Functions Scheduled

Considerable work has been done by the members of the committees which have planned the Pacific Petroleum Chapter Fall Meeting, which will be held October 7 and 8 in the Biltmore Hotel in Los Angeles.

A total of 12 papers will be presented at the Pacific Petroleum Chapter Fall Meeting. Three of these papers will also be given at the Petroleum Branch Fall Meeting in San Antonio and abstracts of them are printed on other pages in this issue.

They are: 401-G, "A Method for Neutron-Derived Porosity for Thin Beds" (page 38); 413-G, "Oil Recovery Performance of Pattern Gas or Water Injection Operations from Model Tests" (page 39); and 424-G, "Radioactive Tracers in Oil Production Problems" (page 40).

In addition to those pictured on this page, other committee workers are H. M. Stanier, Sunray Oil Corp., meeting vice-chairman; Art Langton, Darwin H. Clark Co., exhibits and registration vice-chairman; H. E. Schaller, McCullough Tool Co., arrangements; and E. V. Watts, General Petroleum Corp., dinner dance chairman.

Members of R. S. Crog's Technical Program Committee are: T. D. Mueller, California Research Corp.; Max Taves, Richfield Oil Corp.; H. E. Keegan, Union Oil Co. of California; R. W. Burke, Southwest Exploration Co.; A. J. Horn, Standard Oil Co. of California; E. P. Burtchaell, Kern County Land Co.; W. J. Taylor, Lane-Wells Co.; W. B. Emery II, Ohio Oil Co.; and R. P. Mangold, D. K. Partnerships.

H. C. Pyle
Monterey Oil Co.
General Chairman

R. S. Crog
Union Research Center
Technical Program

S. Patterson
Bankline Oil Co.
Exhibits & Registration

M. E. Loy
Schlumberger
Chm., Pac. Pet. Chap.

Thursday, October 7

8:30 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS — Lobby, Biltmore Hotel Ballroom

9:15 a.m. to 11:30 a.m. — FORMATION EVALUATION — Biltmore Hotel Ballroom

424-G: *Radioactive Tracers in Oil Production Problems*, by A. H. FLAGG, E. S. MARDOCK, J. P. MYERS, J. L. P. CAMPBELL, and J. M. TERRY, Lane-Wells Co.

445-G: *The Contribution of Clays to Formation Resistivity Based upon Laboratory Measurements on Clay Suspensions*, by G. H. SMITH and E. R. ATKINS, JR., Union Oil Co. of California.

401-G: *A Method for Neutron-Derived Porosity for Thin Beds*, by J. M. EDWARDS and A. L. SIMPSON, McCullough Tool Co.

12:00 p.m. — PACIFIC PETROLEUM CHAPTER LUNCHEON — John R. McMillan, Petroleum Branch Chairman, Speaker

2:00 p.m. to 5:00 p.m. — DRAIN HOLE DRILLING — Biltmore Hotel Ballroom

446-G: *The Theory, Application, and Mechanics of Drain Hole Drilling*, by C. WILLIAM ZUBLIN, Universal Engineering Co.

447-G: *Well Productivity Increase from Drain Holes as Measured by Model Studies*, by R. L. PERRINE, California Research Corp.

Panel Discussion on Drain Hole Drilling Covering Techniques and Field Results.

Friday, October 8

8:30 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS — Lobby, Biltmore Hotel Ballroom

9:00 a.m. to 11:30 a.m. — FLUID INJECTION — Biltmore Hotel Ballroom

449-G: *Pressure Maintenance by Water Injection in the Shannon Reservoir, Cole Creek Field, Wyoming*, by C. F. GATES, General Petroleum Corp., and G. G. BROWN, Socony-Vacuum Oil Co., Pegasus Division.

413-G: *Oil Recovery Performance of Pattern Gas or Water Injection Operations from Model Tests*, by F. F. CRAIG, T. M. GEFFEN, and R. A. MORSE, Stanolind Oil and Gas Co.

450-G: *Analysis of Pressure Fall-Off Curves Obtained in Water Injection Wells to Determine Injective Capacity and Formation Damage*, by T. J. NOWAK and G. LESTER, Union Oil Co. of California.

451-G: *Canal Field Gas Injection Project*, by C. J. PINGS, JR., and W. TEMPELAAR LIETZ, Shell Oil Co.

12:00 p.m. — SOUTHERN CALIFORNIA SECTION LUNCHEON — Dr. Richard B. Seynman, Professor of Physics, California Institute of Technology, Speaker

2:00 p.m. — ENGINEERING-MANAGEMENT SPEECH — Biltmore Hotel Ballroom

452-G: *'Idea' Communication*, by E. A. HARTSOOK, Standard Oil Co. of Callfornia.

2:45 p.m. to 4:30 p.m. — OIL FIELD PERFORMANCE — Biltmore Hotel Ballroom

453-G: *Analysis of Reservoir Performance K_g/K_o Curves and a Laboratory K_g/K_o Curve Measured on a Core Sample*, by T. D. MUELLER, J. E. WARREN, and W. J. WEST, California Research Corp.

454-G: *Report of Operations, Naval Petroleum Reserve No. 1, Elk Hills, 1945-1954*, by Commander F. W. GOOCH, JR., USN, and R. H. ADAMS, Standard Oil Co. of California.

7:30 p.m. — PACIFIC PETROLEUM CHAPTER DINNER DANCE — Biltmore Hotel

ABSTRACTS of PAPERS TO BE PRESENTED at PACIFIC PETROLEUM CHAPTER FALL MEETING

445-G

The Contribution of Clays to Formation Resistivity Based Upon Laboratory Measurements on Clay Suspensions

G. H. Smith and E. R. Atkins, Jr.
Union Oil Co. of California

A laboratory investigation of the resistivities of clay slurries in sodium chloride solutions is reported. The resistivity of the filtrate taken from the slurry of a given clay is shown to be different from that of the water used to prepare the solution. This change can be ascribed to solution of salt from the clay or to removal of salt from the solubility of the clay if the latter is initially of low salt content. A term is defined called the "slurry resistivity factor," which is a measure of interference on current passing through an electrolyte solution. Application of this study to interpretation of formation resistivity data from electric logs is indicated.

446-G

The Theory, Application, and Mechanics of Drainhole Drilling

C. William Zublin, *Universal Engineering Co.*

This paper gives basic data concerning drainhole drilling. The uses and advantages of drainhole drilling are explained first. Then, a historical information on the development of drainhole drilling is presented. Finally, the mechanics of the operation are given.

447-G

Well Productivity Increase from Drainholes As Measured by Model Studies

R. L. Perrine, *California Research Corp.*

The paper presents data on the productivity increase that may be expected from use of drainholes. The data were obtained by use of an electrolytic tank model of a reservoir. Parameters varied in the study to show their effect on productivity include the length, number, and arrangement of drainholes, formation thickness, and damage near the wellbore. The most important results are that very large increases in productivity can be expected only in damaged wells. The distance to which drainholes penetrate is of primary importance. Additional length is more effective than increasing the number of drainholes.

449-G

Production Engineering Aspects of Shannon Reservoir, Cole Creek Field, Wyoming

C. F. Gates, *General Petroleum Corp.*, and
G. G. Brown, *Mobil Producing Co.*

Reasonably complete field data have been secured throughout the 14-year life of the Shannon Reservoir. It has a limited natural water drive which is being supplemented by water injection. It has a definite maximum efficient rate, at which it is now being produced. There are enough diverse aspects of the reservoir history to warrant intense study. This paper consists mostly of data and the author's interpretation of the data concerning the reservoir.

450-G

Analysis of Pressure Fall-Off Curves Obtained in Water Injection Wells to Determine Injective Capacity and Formation Damage

T. J. Nowak and Graham Lester
Union Oil Co. of California

The paper presents a practical method of utilizing pressure fall-off data obtained when a water injection well is shut in for determination of: (1) the static reservoir pressure, (2) the potential water injective capacity (md-ft) of the formation, and (3) the formation damage (skin effect) surrounding the wellbore. In the development of the method, equations are presented which give the theoretical background for predicting the behavior of water injection wells. Certain physical factors which limit the application of the method are discussed. The procedure and the relevant precautions in obtaining the data are discussed. A sample analysis and computation from an actual pressure fall-off curve is illustrated. Finally, general characteristics of pressure fall-off curves obtained in several reservoirs are presented.

451-G

Canal Field Gas Injection Project

C. J. Pings, Jr., and W. Tempelaar Lietz
Shell Oil Co.

This history and performance of the Canal oil field, San Joaquin Valley, Calif., are reviewed. A critical examination has been made of the pressure measurements and of the pressure-volume-temperature data for the reservoir fluid. Material balance calculations were employed to determine the original oil in place, the size of the reservoir, the size of the aquifer, the amount of water inflow, and the amount of hydrocarbon migration within the reservoir. The effectiveness of the gas injection program is discussed.

452-G

Idea Communication

E. A. Hartsook, *Standard Oil Co. of California*

As industrial organization becomes more complicated and technical functions more specialized, the problem of communicating ideas and projects has become acute. This paper explains the importance of communication preplanning and the technique of good presentation. The thought is expressed that good idea presentation is a part of technical competence.

453-G

Analysis of Reservoir Performance k_g/k_o Curves and a Laboratory K_g/K_o Curve Measured on a Core Sample

T. D. Mueller, J. E. Warren, and W. J. West
California Research Corp.

The two methods used to obtain the relationship between ratio of gas to oil permeability and gas saturation are to: (1) calculate a curve from field measurements of reservoir behavior, and (2) measure the relationship on a core sample in the laboratory. These curves seldom agree when compared, primarily because the performance k_g/k_o curve is calculated with the assumption of uniform pressure and saturation throughout the reservoir. To show the difference between these curves, two of each were calculated for a hypothetical reservoir. Production performance of the hypothetical reservoir was calculated by use of IBM's 701 Computer. The curves differed, with the performance type curve for the lowest production rate most nearly coinciding with the laboratory curve.

454-G

Report of Operations, Naval Petroleum Reserve No. 1, Elk Hills, 1945-1954

F. W. Gooch, Jr., *Commander, U. S. Navy*, and
R. H. Adams, *Standard Oil Co. of California*

This paper presents the progress of operations within the Elk Hills field for the period 1945 to 1954. Since the shut-in of the field shortly after World War II, many programs have been carried out to maintain the Reserve in a state of readiness whereby it will be able to produce oil in substantial quantities whenever the strategic situation of the United States so requires. Also, an active drilling program is described that has resulted in further development of the Shallow Oil Zone, the exploration and development of the Stevens Zone, and adding a new and as yet untested pool, the Carneros.

Now LARKIN

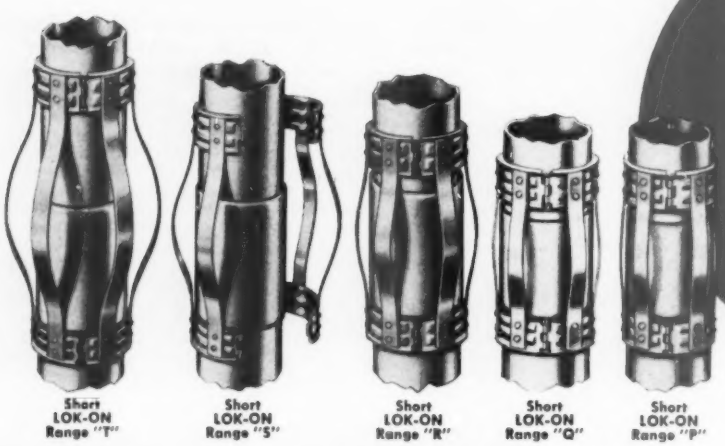
Designed and proved to meet

LONG LOK-ON CENTRALIZER

The Larkin Long Lok-On Casing Centralizer exceeds every known requirement for centralizer performance. To install, LOK-ON around the casing coupling. If other positioning is desirable, plug-weld leg lugs for this purpose are furnished with each centralizer.

SHORT LOK-ON CENTRALIZER

The Larkin Short Lok-On Centralizer is an economical means for centering the shorter strings of casing in undeviated holes. It is being satisfactorily used in many Gulf Coast producing areas.



In the development of these superior centralizers, Larkin engaged the services of a firm of consulting engineers with an established record for ability and integrity, and with a wide range of experience in the developing and designing of oil field equipment. The purpose of this step was two-fold:

1. **To bring the benefits of their experience, their technical ability, and their excellent contacts with oil company engineers into co-ordination with the work being done by Larkin's own engineering department.**
2. **In view of confusion arising from contrasting claims, to be able to place before centralizer users, in certified form, an unbiased and well-documented report, that could be accepted on its merits without regard to purely commercial considerations.**

Every test made in the development of Larkin Centralizers was observed by oil company engineers.

The first step in the development of Larkin Casing Centralizers was to consult with the engineering departments of a large list of oil companies and get their views on what should be expected of a high performance centralizer. The many constructive suggestions thus received were consolidated and our engineers set out to design a centralizer that would meet or exceed the maximum stated requirements. After more than three years of research and testing the final design was established and now a centralizer of truly superior performance is available in a series of ranges and types to suit any well condition, any method of installation, (Slip-On or Lok-On), or to satisfy any need for economy.

FIVE RANGES FOR MAXIMUM EFFICIENCY

Maximum efficiency in a casing centralizer requires a carefully calculated relationship, between the bowed height of the spring and the length of the spring. Therefore, the overall length of centralizers in the various ranges will vary with the size of the hole in which casing of a given size is run. The Range "P" might appear to be rather short just as the Range "T" might appear to be unnecessarily long, but each

OFFERS THE FIRST COMPLETE SELECTION OF CASING CENTRALIZERS

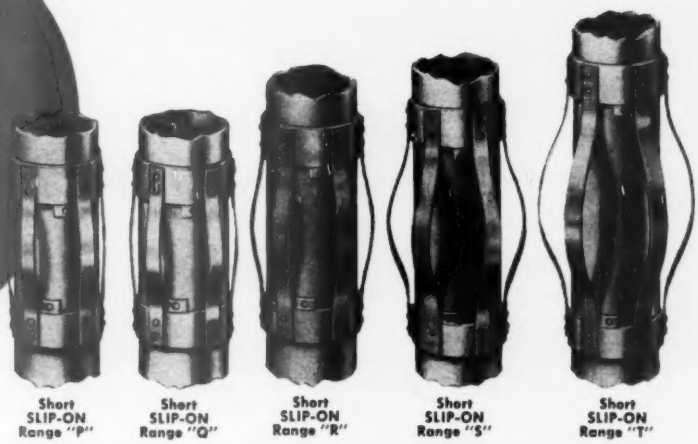
every known requirement

LONG SLIP-ON CENTRALIZER

The Long Slip-On Casing Centralizer is a counterpart of the Larkin Lo-On with the exception that it is always positioned between the casing couplings rather than around them. Where well conditions or personal preference require this type of installation, it is the ideal centralizer.

SHORT SLIP-ON CENTRALIZER

The Short Slip-On Centralizer is an economical unit designed for "between the couplings" installation. It is completely satisfactory for use on short strings in undeviated holes.



Range is scientifically designed to give the operator what he expects from Larkin Centralizers.

IMPORTANT FACTS ABOUT LARKIN CENTRALIZERS

Larkin Centralizers take 45% less permanent set than the maximum usually allowed.

Larkin Centralizers have 300% more initial centering force than the minimum usually required.

Larkin Centralizers of properly selected range will start easily without bumping or snubbing.

HOW TO ORDER

Refer to Selection Charts in the new Larkin Centralizer Catalog and order by Fig. No., casing size and range.

For complete details write for catalog or contact your nearby Larkin representative.

50th Anniversary Year

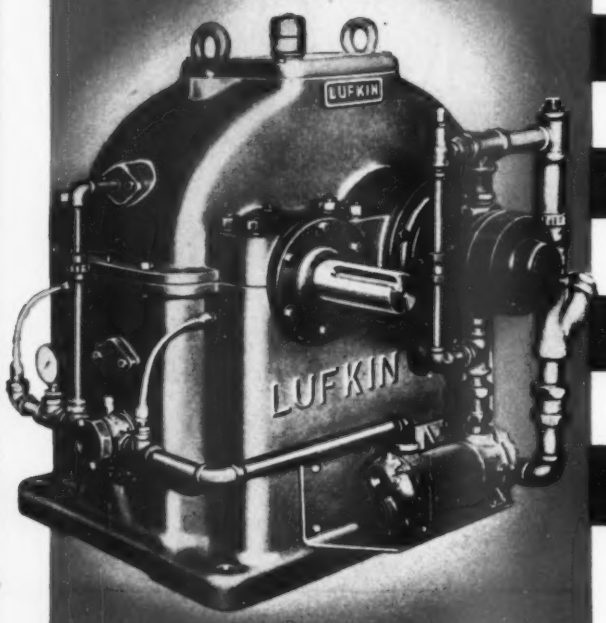
LARKIN

...Through Your Supply Store

LARKIN PACKER COMPANY, INC. • ST. LOUIS, MO.

Lufkin

HERRINGBONE GEAR SPEED REDUCERS AND INCREASERS



LUFKIN, TYPE -N "HIGH SPEED"

ANY SIZE

3 TO 2000 H. P.

ANY SPEED

0 TO 12,000 R. P. M.

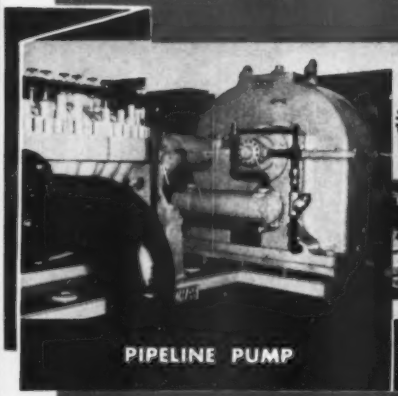
ANY RATIO

1 TO 1 TO 70 TO 1

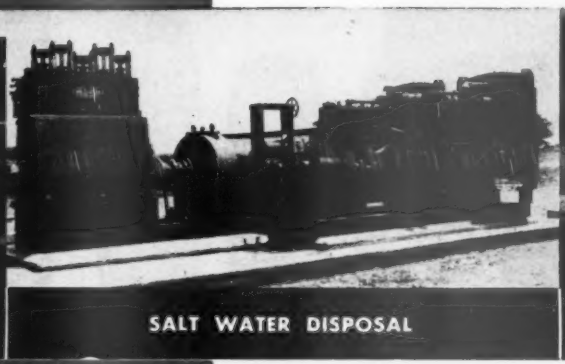
ANY JOB

WHERE SPEED IS REDUCED OR INCREASED . . . . . .

Eighty Different Sizes From Which To Choose



PIPELINE PUMP



SALT WATER DISPOSAL

ALSO SPIRAL BEVEL REDUCERS FOR COOLING TOWERS

LUFKIN FOUNDRY & MACHINE COMPANY

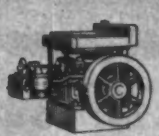
LUFKIN, TEXAS

Branch sales and service Houston, Dallas, New York, Tulsa, Los Angeles, Seminole, Oklahoma City, Corpus Christi, Odessa, Kilgore, Wichita Falls, Casper, Wyoming; Great Bend, Kansas.

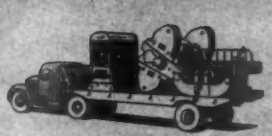
Lufkin Equipment in CANADA is handled by

THE LUFKIN MACHINE CO., LTD. 14321 108th Avenue, Edmonton, Alberta, Canada.

LUFKIN PUMPING UNITS



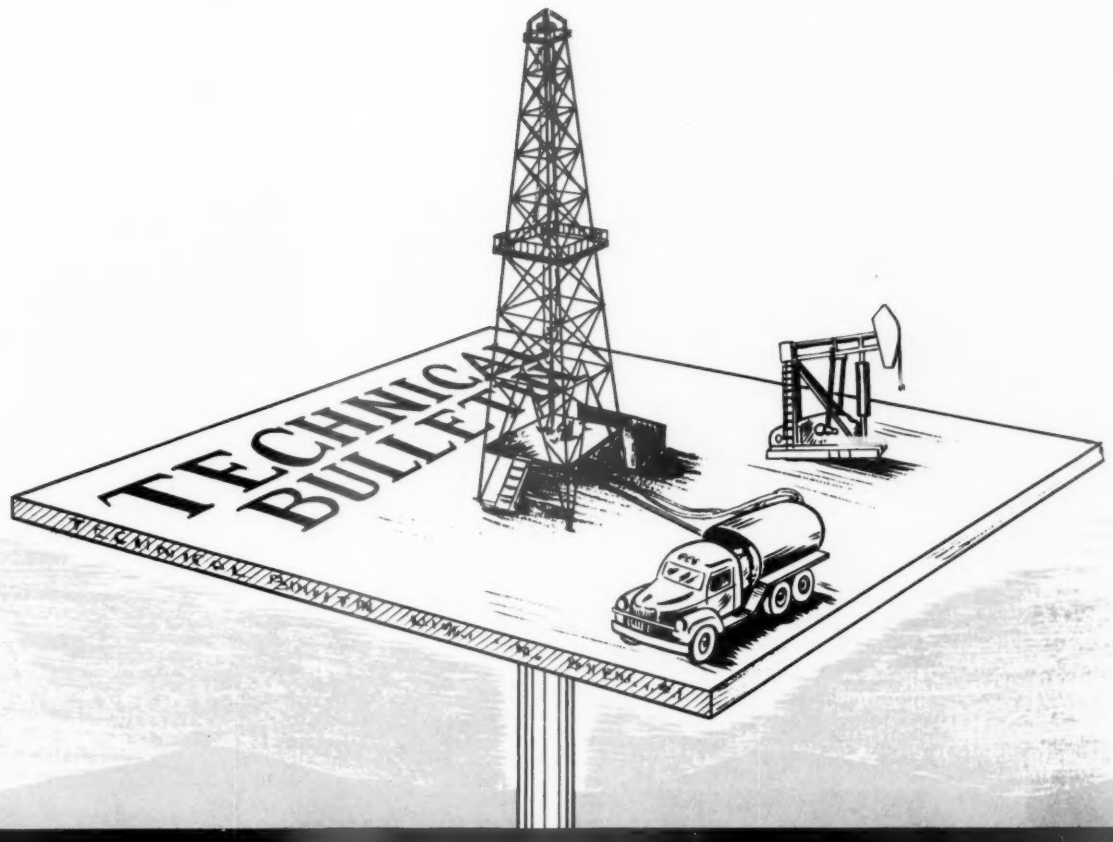
LUFKIN-COOPER-BESSEMER ENGINES



LUFKIN OIL FIELD AND INDUSTRIAL TRUCK TRAILERS

INDUSTRIAL SPEED REDUCERS AND INCREASERS

DIVISION LUFKIN FOUNDRY & MACHINE COMPANY INDUSTRIAL, MILL AND AUTOMOTIVE SUPPLIES



JOURNAL OF PETROLEUM TECHNOLOGY

Presents

THE TECHNICAL SALES BULLETINS

of the Equipment and Service Companies

Who Serve the AIME Market

FROM the EXECUTIVE SECRETARY

Dear Reader:

We commend to you the reading of the following section of this magazine which contains technical bulletins of equipment and service companies serving the Petroleum Branch, AIME membership. We believe you will find this technical information valuable and will look with favor upon those companies which compliment you by placing their technical bulletins here for your convenience.

JOE B. ALFORD

INDEX to PRODUCTS and SERVICES DESCRIBED in TECHNICAL BULLETIN SECTION

A

AMERICAN IRON & MACHINE WORKS CO.
- Type "HD" Hydraulic-Mechanical Packer Holddown

ASSOCIATED EQUIPMENT, INC.
- Acoustical Well Sounder

B

BAKER OIL TOOLS, INC.
- Baker Model "H" Hinge-Lok Casing Centralizer
- Baker Roto-Vert Casing Scraper

BAROID SALES DIVISION
- Automatic Recording Gas Detector

G

GARRETT OIL TOOLS, INC.
- Automatic Tank Switching Systems
- Permanent Completions Equipment and Services

GEOLOGRAPH CO.
- Mechanical Well-Logging Service

H

HYDRIL CO.
- Blowout Prevention Control Equipment

J

JOHNSTON TESTERS, INC.
- Type B Hydraulic Tester
- Type BT Open Hole Packer

K

KINZBACH TOOL CO., INC.
- Model 112 Automatic Relief Valve

O

OIL CENTER TOOL CO.
- G.C.T. "C-19" Casing Heads

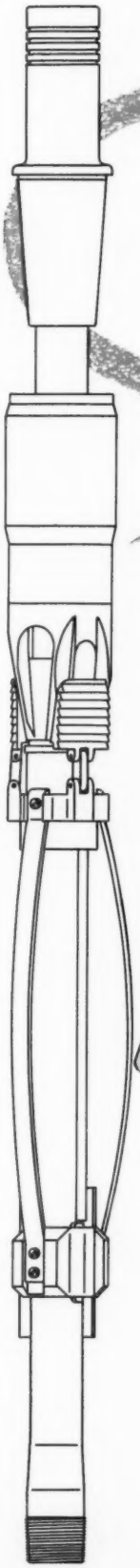
S

SCHLUMBERGER WELL SURVEYING CORP.
- Radioactivity Logging

T

TRETOLITE CO.
- Kontol Corrosion Inhibitors
- Solvo Paraffin Removers
- Tret-o-lite Demulsifiers
- Tret-o-lite Desalting
- Tret-o-lite Scale Preventives
- Tret-o-lite Water De-Oilers

American Iron's new *ALL RUBBER* cup!



SEALS pressures in excess of

8,000 lbs. at 300°F

NOW TYPE S PACKER IS MORE EFFECTIVE THAN EVER!

American Iron's remarkable, NEW "all-rubber" packer cup has the lowest vulcanization point of any resilient material! No more sticking of cup to mandrel or casing wall at high pressures and temperatures. Cup returns to original shape when packer is unset! And, with this new cup, your Type "S" Packer will set at a lower tubing load, removing dangers of putting compression loads on tubing.

- New "all-rubber" cup sets at a minimum tubing load!
- New cup has low vulcanization point, yet is highly resilient!
- New cup is highly resistant to petroleum products, mild acids, and hydrogen sulfide gas!
- New cup will seal pressures in excess of 8000 lbs. at 300°F!

POSITIVE SETTING No complicated, intricate setting procedures to be followed. Setting of slips is accomplished with a simple key-and-open-slot arrangement—no troublesome J-tools to fail. Furnished either right or left hand set.

POSITIVE RELEASE Dovetail guide on the slip mandrel insures positive release when packer is retrieved. Slips expand on a flat tapered surface which increases the area of contact, preventing the collapse of the slip mandrel or breakage in the slips.

AMERICAN IRON & MACHINE WORKS CO.
MANUFACTURERS OF OIL FIELD EQUIPMENT
A
REG. U.S. PAT. OFF.
OKLAHOMA CITY U.S.A.

over

The Packer Holddown that doesn't "walk" up hole when pressure is applied from below!

American Iron Type HD Packer Holddown is the only packer holddown on the market that can be released without first equalizing pressures above and below packer.

Makes TYPE S PACKER more effective than ever!

This American Iron Type HD Packer Holddown is designed to hold the packer in place in applications where pressure below the packer is considerably greater than pressure above. When Type HD Packer Holddown is set, you are assured of a positive anchor by a combination hydraulic and mechanical latch.

In releasing this Type HD Packer Holddown there are no extra valves or pressure release mechanisms to contend with; merely pick up on tubing, which in turn lifts slip mandrel and releases dovetail type slips from casing.

Recommended especially for

- High Pressure Acidizing
- Formation Fracturing
- Water Flood Input Wells

AMERICAN IRON & MACHINE WORKS CO.

Oklahoma City, Oklahoma • Box 1177

over

NEW-IMPROVED

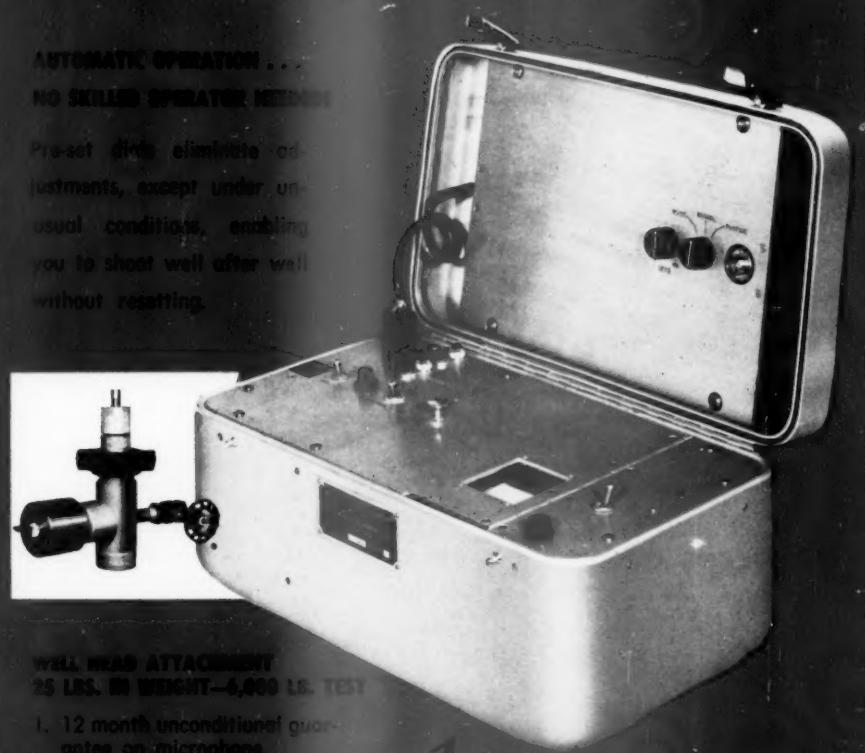
Acoustical Well Sounder

(Field Level Recorder)

SAVES TIME — MONEY — OPERATIONAL COSTS

AUTOMATIC OPERATION . . .
NO SKILLED OPERATOR NEEDED

Pre-set dials eliminate adjustments, except under unusual conditions, enabling you to shoot well after well without resetting.



WELL HEAD ATTACHMENT
25 LBS. IN WEIGHT—4,000 LB. TEST

1. 12 month unconditional guarantee on microphone.
2. Firing mechanism easily disassembled for cleaning.

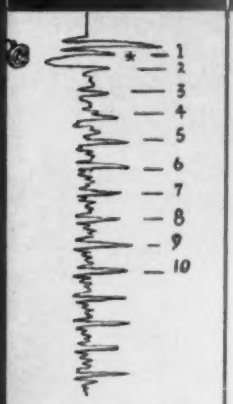
WEATHER PROOF! WILL FLOAT!

Can be made submersion proof on order.

AMPLIFIER-RECORDER ONLY 30 LBS. IN WEIGHT

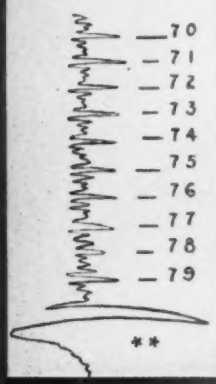
A single compact unit in a 16"x9"x8" aluminum case. Plug in construction for ease of repair. Maintenance is reduced to a minimum. Power—6 volt automobile battery.

from top



*Note clear indication of first collar

**Note clear indication of fluid level



to bottom

A PERFECT LOG . . .

New design eliminates need for dual trace recording.

Routine recordings at 9,000 feet.

Price Complete

$2915.00

Lease Instrument

Available to Service & Producing Companies

ASSOCIATED EQUIPMENT INC.

P. O. BOX 6067 HOUSTON, TEXAS

ASSOCIATED EQUIPMENT INC. — DEPT. D
P. O. Box 6067 — Houston, Texas

Please Send Me Complete Information On Your New Acoustical Well Sounder.

FIRM: _____

BY: _____

ADDRESS: _____

Acoustical Well Sounder. . .

SALES AND SERVICE

OFFERED IN THE FOLLOWING LOCATIONS

ASSOCIATED ENGINEERS, INC.
P. O. BOX 6067
HOUSTON, TEXAS

ASSOCIATED ENGINEERS, INC.
P. O. BOX 321
ALICE, TEXAS

ASSOCIATED ENGINEERS, INC.
P. O. BOX 721
JENNINGS, LA.

BENNETT-BURNS ENGR. & EQPT., LTD.
1606 10TH AVE.
REGINA, SASKATCHEWAN
CANADA

CHEMICAL & GEOLOGICAL LABS., INC.
EDMONTON, ALBERTA
CANADA

CHEMICAL & GEOLOGICAL LABS., INC.
521 SO. CENTER ST.
CASPER, WYOMING

BILL G. HARMON
P. O. BOX 309
CARMI, ILL.

HUDSON-EADS, INC.
609 CITY NATIONAL BLDG.
WICHITA FALLS, TEXAS

WEST TEXAS ENGINEERING SERVICE, INC.
P. O. BOX 2464
MIDLAND, TEXAS

ADDITIONAL NEW SERVICE AREAS ARE NOW OPEN

Complete Information Furnished Upon Request

ASSOCIATED EQUIPMENT, INC.

P. O. Box 6067 • Houston, Texas

Bulletin No. 309

BAKER

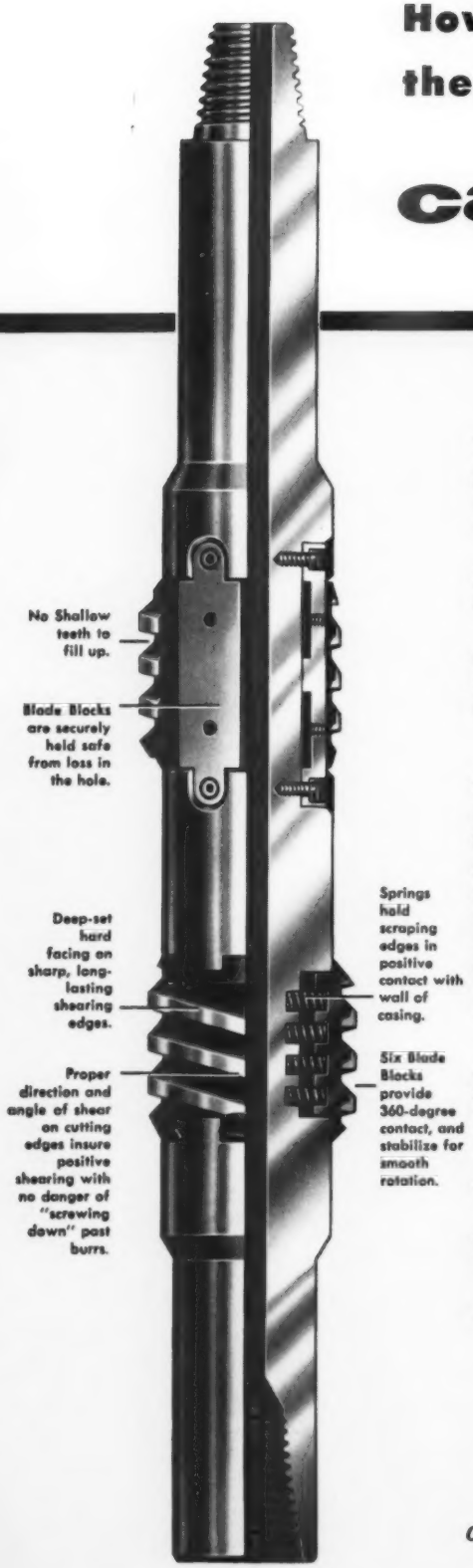
"MODEL C"

ROTO-VERT CASING SCRAPER

PRODUCT NO. 620-C

How important is it to have the inside of your

casing smooth


No Shallow teeth to fill up.
Blade Blocks are securely held safe from loss in the hole.
Deep-set hard facing on sharp, long-lasting shearing edges.
Proper direction and angle of shear on cutting edges insure positive shearing with no danger of "screwing down" past burrs.
Springs hold scraping edges in positive contact with wall of casing.
Six Blade Blocks provide 360-degree contact, and stabilize for smooth rotation.

Not only is it important to have clean casing *when a well is being completed,* but consider also the advantages of being able to *proceed safely with any future down-hole work,* knowing that the vital "working surface" (the I. D.) of your casing is *clean and free of all obstructions.*

Hardened mud or cement, burrs from gun-shot perforations, and even mill scale are all hazardous when you run testers or swabs, or undertake to set cement retainers, bridge plugs or packers.

With a Baker Model "C" ROTO-VERT Casing Scraper you can quickly, safely and economically remove harmful obstructions from the inside of the casing, leaving it clean and smooth for any future down-hole operations.

RUN A ROTO-VERT WHEN DRILLING OUT

The best time to use a ROTO-VERT Casing Scraper is when drilling out cement, by running it as a "follow-up" behind the bit. It is recommended that the ROTO-VERT first be lowered through the perforated area *without rotation,* to dislodge any possible imbedded bullets; then raise the Scraper above the perforated area and rotate down the hole and complete the work of drilling out cement. In a *single run* you not only "drill out", but at the same time remove all hardened cement, mud, burrs and scale which might otherwise later *damage swab or tester rubbers* and cause packers, bridge plugs or retainers to *set prematurely*—or *never set at all.*

ROTO-VERT SUPERIOR IN DESIGN AND PERFORMANCE

No other casing scraper can equal the results obtained by the Baker ROTO-VERT, because . . .

1. The *direction and angle of shear* of the cutting edges is OPPOSITE TO THE DIRECTION OF ROTATION. There is no possibility of "screwing down" past obstructions during rotation;

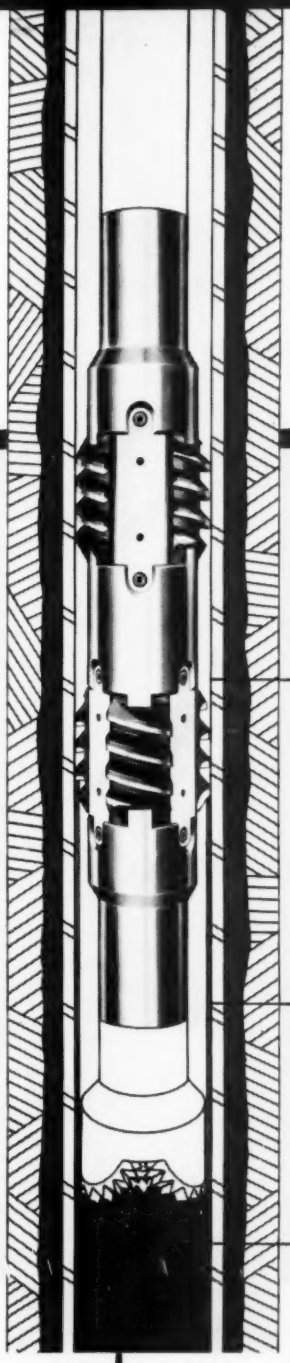
2. The shearing edge of the Blades on the ROTO-VERT is set at *only a slight angle from the horizontal.* This minimizes torque and vibration, and places far less strain on the Blade Blocks and the entire assembly;

3. The six rugged Blade Blocks are positioned to overlap for full 360-degree scraping coverage.

For consultation and service on Baker ROTO-VERT Casing Scrapers...

call BAKER

and clean?



Even when a maximum gauge bit is used for drilling-out, a thin sheath of hardened cement remains to interfere with future operations. To visualize how ROTO-VERT removes this sheath, see left.

All cement, scale, burrs, etc., have been removed by the ROTO-VERT Scraper, and the vital "working surface" of casing is left clean and smooth.

This thin sheath of hardened cement always remains after the bit has passed.

Cement to be drilled out.

With these features you are assured that all coatings and obstructions are scraped away and completely removed. No bullets or burrs are left—no hardened cement remains to present hazards to future operations.

ROTO-VERT CAN ALSO BE RUN ON TUBING OR A WIRE LINE

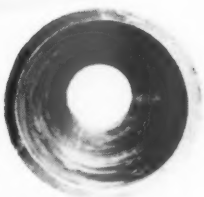
On old wells (or where rotary equipment is not present) the Baker ROTO-VERT Casing Scrapers can be run on tubing, or on a wire line equipped with sinker bars and jars. Spudding action usually quickly removes hardened cement, mud or other coatings WITHOUT ROTATION and clears up any rough or stubborn tight spots. While imbedded bullets usually are dislodged, and burrs smoothed up, "spudding" cannot be expected to give results equal to those obtained by "rotary shearing" of metal obstructions.

EASY AND ECONOMICAL TO RUN

The Baker ROTO-VERT Casing Scraper is readily used by any experienced driller. No service man is required, and the low rental cost is returned many times over in averting future damage to swab rubbers, and to packing elements on bridge plugs, retainers or packers. Elimination of future delays, and re-run expense is also an important consideration.

BAKER OIL TOOLS, INC.

HOUSTON • LOS ANGELES • NEW YORK



Here's how ROTO-VERT shears away dangerous burrs and leaves the casing safe for all future operations.

Burrs like this can cause plenty of trouble, unless . . .

This packing rubber would not have been ripped by a gun-shot burr if a ROTO-VERT Scraper had been used.

The brittle cement sheath (above) prevents the slips of pack-off tools from gripping the casing. See (at left) how slips tried, unsuccessfully, to set against the cement sheath.

. . . they are sheared and scraped smooth with the ROTO-VERT.

Specifications and Instructions for Ordering

Specifications: Complete specifications covering the Baker Model "C" ROTO-VERT Casing Scraper are shown in the Specification Guide below. The Guide indicates the size numbers of the six basic sizes of Casing Scraper Bodies; the full range of casing sizes, as well as casing I.D.'s for which each Body can be used; and the maximum O.D. of each Body. In addition, the Specification Guide gives the size numbers of the Casing Scraper Blade Blocks for use with the corresponding Casing Scraper Body, together with the full range of casing I.D.'s for which each Blade Block can be used.

Instructions for Ordering: In ordering a Baker Model "C" ROTO-VERT Casing Scraper, be sure to furnish the information detailed below.

1. Size Number of Casing Scraper Body desired.
2. Size and type of thread connections desired on Body.
3. Size number of Blade Block. (Give complete Size Number as shown in Master Specification Guide.)
4. Size, type, and weight of casing in which the Casing Scraper and Blade Blocks are to be run.

MASTER SPECIFICATION GUIDE

Baker Model "C" Roto-Vert Casing Scraper

Product No. 620-C

Size Number of Scraper	Casing O.D.	Weight in Pounds Threaded & Coupled Casing	Weight in Pounds Internal Upset Casing	Range of Casing I.D.'s in which Scraper may be Run		Size and Type of Threaded Connection Pin Up-Box Dn	Diameter of Circulating Hole Through Body	Maximum O.D. of Body	Size Number of Blade Blocks
				Minimum	Maximum				
10	4½" 4¾"	9.5-16.6 16-21	11.6-13.5 16-18	3.823	4.090	2⅜" A.P.I. Reg.	1"	3½"	10
11	4½" 4¾" 5" 5½"	6.75-9.5 7.25-9.5 11.5-21 25	.... 15-21 25	4.090	4.580	2⅜" A.P.I. Reg.	1"	3¾"	11
12	5½" 5¾"	15.5-23	15.5-23* 25.2	4.670	4.950	2⅞" A.P.I. Reg.	1⅛"	4¼"	12A
12	5½" 5¾" 6"	13-17 17-22.5 23-26	..... 19.5*-22.5* 23-26	4.892	5.240	2⅞" A.P.I. Reg.	1⅛"	4¼"	12B
12	5¾" 6" 6⅝"	14 14-20	..... 18*-20* 34	5.290	5.620	2⅞" A.P.I Reg.	1⅛"	4¼"	12C
14	6⅝" 7"	20-32 34-40	24-32 33.7-40	5.615	6.065	3½" A.P.I. Reg.	1¼"	5¼"	14A
14	6⅝" 7" 7⅝"	17 17-32 45	..... 23-32* 45	6.066	6.538	3½" A.P.I. Reg.	1¼"	5¼"	14B
14	7⅝"	20-39	26.4-39	6.539	7.125	3½" A.P.I. Reg.	1¼"	5¼"	14C
16	8⅝" 9"	24-49 45-55	32-49 45-50.2	7.421	8.097	4½"A.P.I. Reg.	2"	7"	16A
16	9" 9⅝"	34-40 53.5-58	34-40 53.5-58	8.098	8.594	4½" A.P.I. Reg.	2"	7"	16AB
16	9⅝"	29.3-47	40-47	8.595	9.063	4½" A.P.I. Reg.	2"	7"	16B
18	10¾"	32.75-55.5	.....	9.750	10.192	6⅝" A.P.I. Reg.	2¼"	9¼"	18A
18	11¾"	38-60	.....	10.772	11.150	6⅝" A.P.I. Reg.	2¼"	9¼"	18B

*Internal Upset Bored Joint of this weight is smaller than recommended minimum casing I.D. to run in. Scraper may be run through the joints of the Internal Upset Casing specified, but is not recommended to scrape an I.D. smaller than minimum shown.

BAKER OIL TOOLS, INC.
HOUSTON • LOS ANGELES • NEW YORK

PRINTED IN U.S.A.

20M 8-54

The immediate acceptance of casing centralizers by oil operators, and the phenomenal increase in their use, proves far better than words that

"Centering the casing pays off"

By centering the casing, the hazard of channeling is far less. Effective water shut-offs are secured and a permanent casing installation results. With knowledge based upon years of cooperation in cementing operations, Baker offers a complete line of Casing Centralizers practically "tailor made" to meet your most exacting requirements.

Turn the page for illustrations and explanation

A New member of a distinguished family—

BAKER MODEL "H"
15-Range HINGE-LOK
Casing Centralizer
Product No. 9115
For easy starting
in "slim" holes.

Introducing the new Baker "H-15" HINGE-LOK Casing Centralizer . . .

To meet the requirement for a casing centralizer which can be started in "slim" holes, without the application of external force, Baker now offers the Model "H" *15-Range* HINGE-LOK Casing Centralizer. It is also successfully used on the first few joints—for easy starting—followed by Baker Centralizers with greater bowed height to center the casing when the hole is over-size or irregular in bore size.

"Reach" (Bowed Height) of Springs is vital factor

Where well conditions require the use of centralizers which provide *ease of starting* combined with *maximum "reach"* (bowed height of springs) to ensure a positive, uniform annular cementing space around the casing, you can select the range of Baker HINGE-LOK Casing Centralizer truly "tailor-made" for your needs.

The increased reach provides adequate, all-around cementing space even though the hole size varies considerably from the drill bit size. Without such increased reach, there always is danger that the casing will contact the wall of the hole between centralizers, and a poor cement job at that point will follow.

HINGE-LOK permits fast, easy mounting

Baker HINGE-LOK Casing Centralizers are *installed in a matter of seconds* while running-in, as *no welding is required.* Simply close the HINGE-LOK Centralizer around a coupling—then insert drive nails which *thread themselves* into the hinge knuckles and *will not come out.* When exact spacing is desired, easily installed Stop Rings are plug-welded at required positions. Either mounting method permits unlimited free rotation of the casing *without* rotation of the centralizers.

Easily Started WITHOUT "Snubbing"

By properly selecting and spacing centralizers of suitable range, all need for applying external starting force is eliminated, even in "slim" holes. The superior spring design of Baker HINGE-LOK Casing Centralizers permits easy starting, but the powerful centering force remains after reaching the desired cementing point.

Maximum effective centering force

Inasmuch as the primary function of any casing centralizer is to provide a *positive, uniform annular cementing space around the casing,* the "maximum effective centering force" is likewise of primary importance. Baker HINGE-LOK Casing Centralizers provide the *desired cementing space at the cementing point* regardless of repeated flattening of the springs. This advantage is especially desirable in off-vertical holes.

The engineered bow shape of the springs, with an ideal relationship between the length and the bowed height of the springs, provides *maximum landed centering force* in any combination of casing sizes and open hole sizes.

Call BAKER for "Resultful" Centralizer Service

Just call any Baker representative or office for the kind of service every operator appreciates—sincere, courteous assistance to help you get successful "first-time" Cementing results.

BAKER OIL TOOLS, INC.
HOUSTON • LOS ANGELES • NEW YORK

BAKER MODEL "H" 20-Range HINGE-LOK Casing Centralizer • Product No. 9112

Recommended where LESS-THAN-NORMAL CLEARANCE exists between the casing ON which the centralizers are mounted and the casing THROUGH which the centralizers are run. In cases of over-size or irregularity of the open hole, it is often advisable to run the "H-20" Centralizer on the first few joints—for ease in starting—followed by the "H-25" or the "H-50" Super-Range Centralizer.

BAKER MODEL "H" 25-Range HINGE-LOK Casing Centralizer • Product No. 9113

Recommended where NORMAL CLEARANCE is present, and no serious problem of over-size hole is anticipated. The "H-25" Centralizer is recommended where conditions are such that starting force would be a problem with the "H-50" Super-Range Centralizer, in which case the H-25 might be used on the first few joints and the H-50 run above it. Although the H-50 requires a larger spacing interval for easy starting than centralizers having a smaller range, fewer "H-50" Centralizers—with their superior reach—ensure even greater effective centering force.

WITH

BAKER

HINGE-LOK

CASING CENTRALIZERS

you are sure to get MAXIMUM CENTERING FORCE throughout the zone to be cemented.

BAKER MODEL "H-50" Super-Range HINGE-LOK Casing Centralizer • Product No. 9114

Recommended for GREATER-THAN-NORMAL CLEARANCE—wherever the diametral clearance between the casing ON which the centralizers are mounted, and the casing THROUGH which they are to run exceeds five inches; or for NORMAL CLEARANCE where extensive hole irregularities are anticipated. No other centralizer can provide such effective centering action as the "H-50" in *irregular or over-size hole sections, or in cavities.* By increasing the bow of the springs (without proportionately increasing their resistance to starting) maximum centering efficiency is assured, regardless of individual well conditions.

Before you run another string of casing...

it will pay you well to contact the Baker representative in your area. His knowledge of field conditions, formations, and casing and completion programs will enable him to give you practical, helpful suggestions for successful casing centering, combined with modern preparation of the formation by using Baker Wall Scratchers. Cementing is surely the most important feature in placing your well upon a permanent, profit-making basis. The odds will be in your favor when you "Call Baker First."

SPECIFICATION GUIDE

To determine the most efficient range of centralizer for any given program, start with the size of casing ON which a centralizer is to be run (Column 1) and the ACTUAL size of open hole where the centralizer is to be positioned (Column 2). The size and most efficient range of centralizer will be found in Column 3. If the casing through which the centralizer is to be run is smaller than shown in Column 4, however, the next smaller range must be used to avert starting difficulty. Refer to Starting Force Spacing Guide, Page 466 of the Baker (or Composite) Catalog, for minimum spacing between centralizers to ensure easy starting without the application of external force.

Columns 5 and 6 are for purposes of information. The figures in Column 6 indicate minimum O.D.'s when centralizer is mounted over couplings. When centralizer is placed over Stop Rings, these minimum O.D.'s can be reduced ¼".

NOTE: The hole sizes shown in Column 2 represent the ACTUAL OPEN-HOLE SIZE AT THE POINT WHERE THE CENTRALIZER WILL BE WHEN IN CEMENTING POSITION, and may or may not correspond to bit size. In the absence of a caliper log or past records, however, the bit size should be used as the hole size.

Where sections of the open hole are irregularly over-size to such an extent that more than one range of HINGE-LOK Casing Centralizer is called for (example: H-25's and H-50's), it is recommended that the larger of the two choices be used (consistent with Column 4 and the Starting Force Spacing Guide), unless an engineered string of mixed ranges is practicable.

BAKER
OIL TOOLS, INC.
HOUSTON • LOS ANGELES • NEW YORK

Specification Guide

BAKER
MODEL "H"
CASING CENTRALIZER
PRODUCT NOS. 9115, 9112, 9113, 9114

Size of Casing To Run On (1)	Recommended Range of Actual Open Hole (2)	BAKER CENTRALIZER SIZE NO. (3)	Minimum Size Casing To Run Thru for Easy Starting (4)	CENTRALIZER O.D. Maximum (5)	CENTRALIZER O.D. Minimum (6)
4½"	6¼"— 6⅞" 7" — 9" 9⅛" & Up	†4½ H-15 4½ H-20 4½ H-25 4½ H-50	7⅝" † 7⅝" 8⅝" 8⅞"	7⅞" 8⅞" 10" 15"	5⅝"
5"	6⅜"— 7¼" 7⅜"— 9½" 9⅝" & Up	†5 H-15 5 H-20 5 H-25 5 H-50	7⅝" *† 7⅝" 8⅝" 8⅝"	8⅜" 9⅜" 10½" 15½"	6 3/16"
5½"	7" — 7⅞" 8" — 9⅞" 10" & UP	†5½ H-15 5½ H-20 5½ H-25 5½ H-50	8⅝" † 8⅝" 9⅝" 9⅝"	8⅞" 9⅞" 11" 16"	6 11/16"
6"	8" — 8⅞" 9" —10½" 10⅝" & Up	6 H-20 6 H-25 6 H-50	9⅝" 10¾" 10¾"	10⅜" 11½" 16½"	7¼"
6⅝"	8¼"— 9⅛" 9¼"—11" 11¼ & Up	6⅝ H-20 6⅝ H-25 6⅝ H-50	9⅝" 10¾" 10¾"	11" 12⅛" 17⅛"	8"
7"	8⅜"— 9⅜" 9½"—11½" 11¾" & Up	†7 H-15 7 H-20 7 H-25 7 H-50	9⅝" † 9⅝" 10¾" 10¾"	10⅜" 11⅜" 12½ 17½"	8¼"
7⅝"	9½"—10⅜" 10½"—11¾" 12" & Up	7⅝ H-20 7⅝ H-25 7⅝ H-50	10¾" 11¾" 11¾"	12" 13⅛" 18⅛"	9⅛"
8⅝"	10⅝"—11⅜" 11½"—13" 13¼" & Up	8⅝ H-20 8⅝ H-25 8⅝ H-50	11¾" 12¾" 12¾"	13" 14⅛" 19⅛"	10¼"
9⅝"	11¾"—14" 14¼ & Up	9⅝ H-25 9⅝ H-50	13⅜" 13⅜"	15⅛" 20⅛"	11¼"
10¾"	13" —15¼" 15½" & Up	10¾ H-25 10¾ H-50	16" 16"	16¼" 21¼"	12⅜"
11¾"	14½"—16¼" 16½" & Up	11¾ H-25 11¾ H-50	16" 16"	17¼" 22¼"	13⅜"
12¾"	15" —17¼" 17½" & Up	12¾ H-25 12¾ H-50	....	18¼" 23¼"	14⅝"
13⅜"	16" —17¾" 18" & Up	13⅜ H-25 13⅜ H-50	....	18⅞" 23⅞"	15"
16"	18½"—20½" 20¾" & Up	16 H-25 16 H-50	....	21½" 26½"	17⅝"

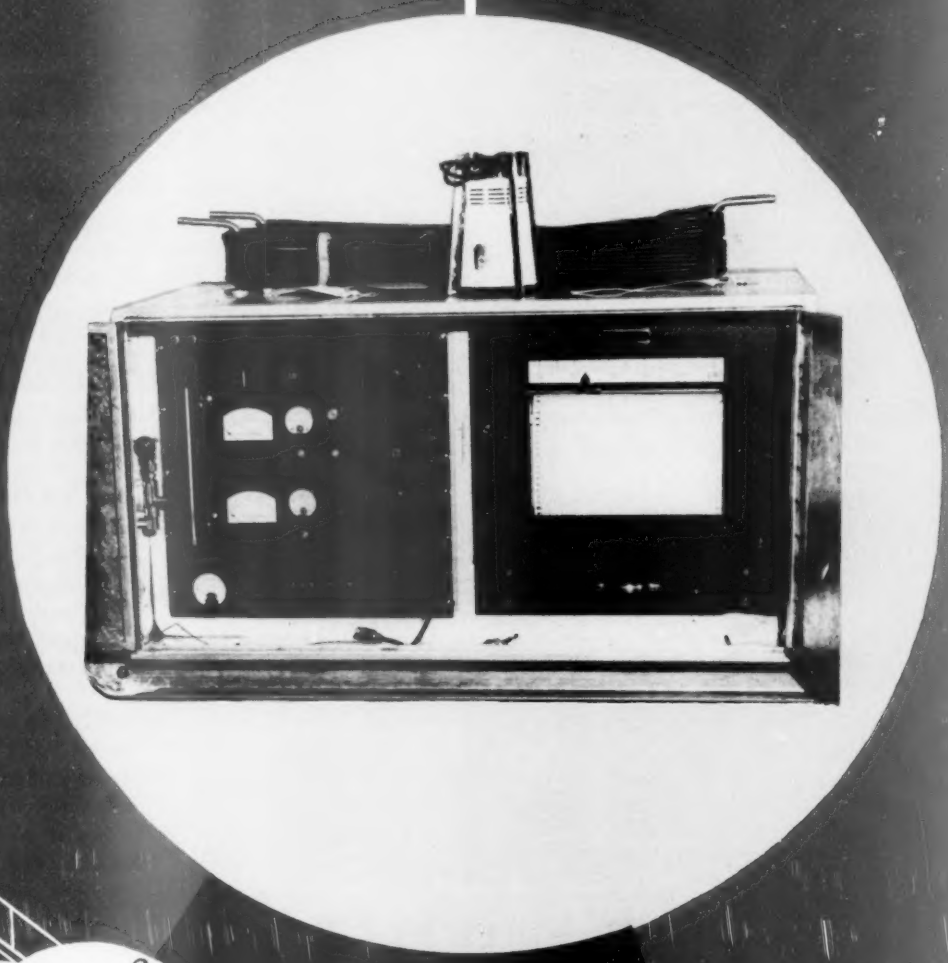
* Check bit size for heavy weights to be sure it falls within recommended range of hole sizes.

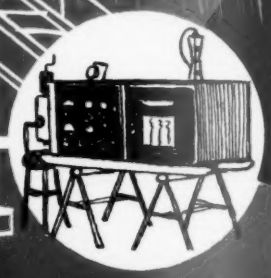
† Where the required spacing is closer than that in which the H-20 can conveniently be started, the H-15 may be used, even though the centering force per unit will be slightly diminished.

PRINTED IN U.S.A.

20M 8-54

AUTOMATIC RECORDING GAS DETECTOR





BAROID

WELL LOGGING SERVICE

AUTOMATIC RECORDING GAS

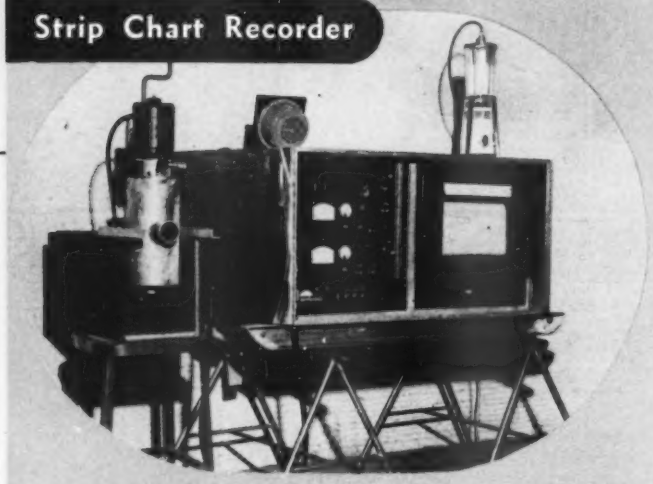
Baroid Well Logging Service in its never ending effort to fill the industry's needs in its search for oil and gas, has engineered and built for its customers the BAROID AUTOMATIC RECORDING GAS DETECTOR.

This instrument can be readily installed at the well site and has been designed expressly for the well-site geologist! Up to the present time, the geologist on the well has had a microscope and some form of ultraviolet lamp to aid him in determining the type of formation drilled, and to observe oil staining and fluorescence in cuttings samples accumulated over 20 to 30 foot intervals. Now he can pinpoint all possible productive gas and/or oil horizons as drilling progresses, since the BAROID AUTOMATIC RECORDING GAS DETECTOR will automatically and continuously detect and record gas zones for him as they are penetrated by the bit.

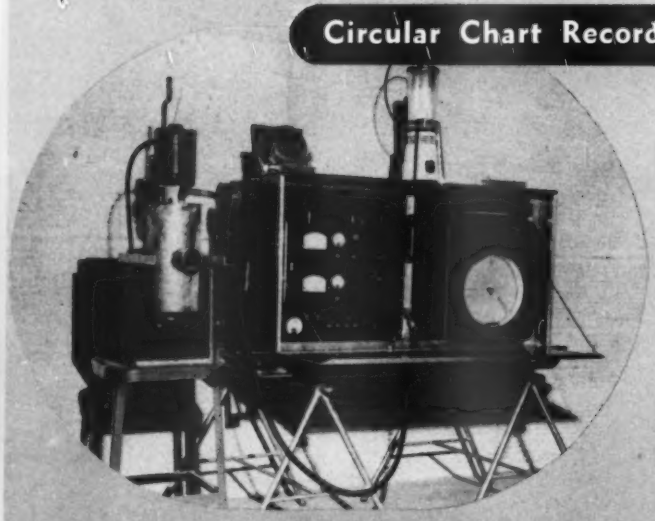
Essentially, this instrument is a portable version of the newest gas detecting and recording equipment, designed by our research engineers and used in Baroid's Well Logging trucks. The unit consists of the following:

- CONTINUOUS MUD GAS DETECTOR. This is the Baroid engineered hot wire gas detector with new type Baroid vertical, complete agitation trap to remove the gas from the mud that passes through it.
- GAS RECORDER. Either a strip chart recorder or a circular chart recorder is available to record continuously and automatically the total gas and methane curves from the mud gas detector. An alarm horn is incorporated in the instrument to warn the geologist of increases in gas readings.
- CUTTINGS GAS DETECTOR. This equipment enables the geologist to make gas determinations on cuttings samples. This batch determination can be made continuously or whenever the mud gas detector indicates that a possible oil or gas horizon has been encountered.

Strip Chart Recorder



Circular Chart Recorder



Since early in 1953, many of the major oil companies have demonstrated the need and effectiveness of this new Baroid development by its use on field wells, outpost wells and wildcat wells where complete well logging units are not employed.

DETECTOR

Some of the many ways BAROID'S AUTOMATIC RECORDING GAS DETECTOR has proven an inexpensive and valuable tool in helping field geologists carry out their well programs are as follows:

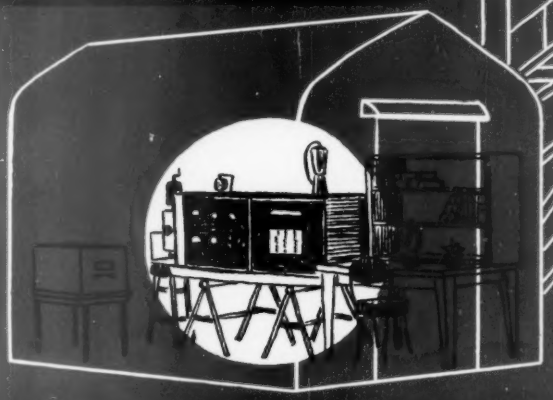
- **Determining Coring Points.**
- **Determining which Zones to DST.**
- **Selecting Side Wall Coring Points.**
- **Aiding in Interpretation of Electric Logs.**
- **Warning against Possible Blowouts.**
- **Selecting Perforating Zones.**

INSTALLATION OPERATION MAINTENANCE

The unit is readily installed and can be easily maintained and operated by your geologist with a minimum of instruction from one of our trained engineers.

The complete unit is built compactly into a reasonably weather-proofed aluminum cabinet approximately 4′ x 2′ x 1½′, and weighs about 350 lbs. It requires less than 300 watts of electrical power and can be operated from any 115 volt source, either AC or DC.

The unit can be set up in a semi-protected area near the flowline or may be installed in the geologist's field trailer or "sample" house. This latter arrangement has proven particularly efficient, as it can be closely watched while the geologist is examining cuttings samples.



Installed in "Sample" House

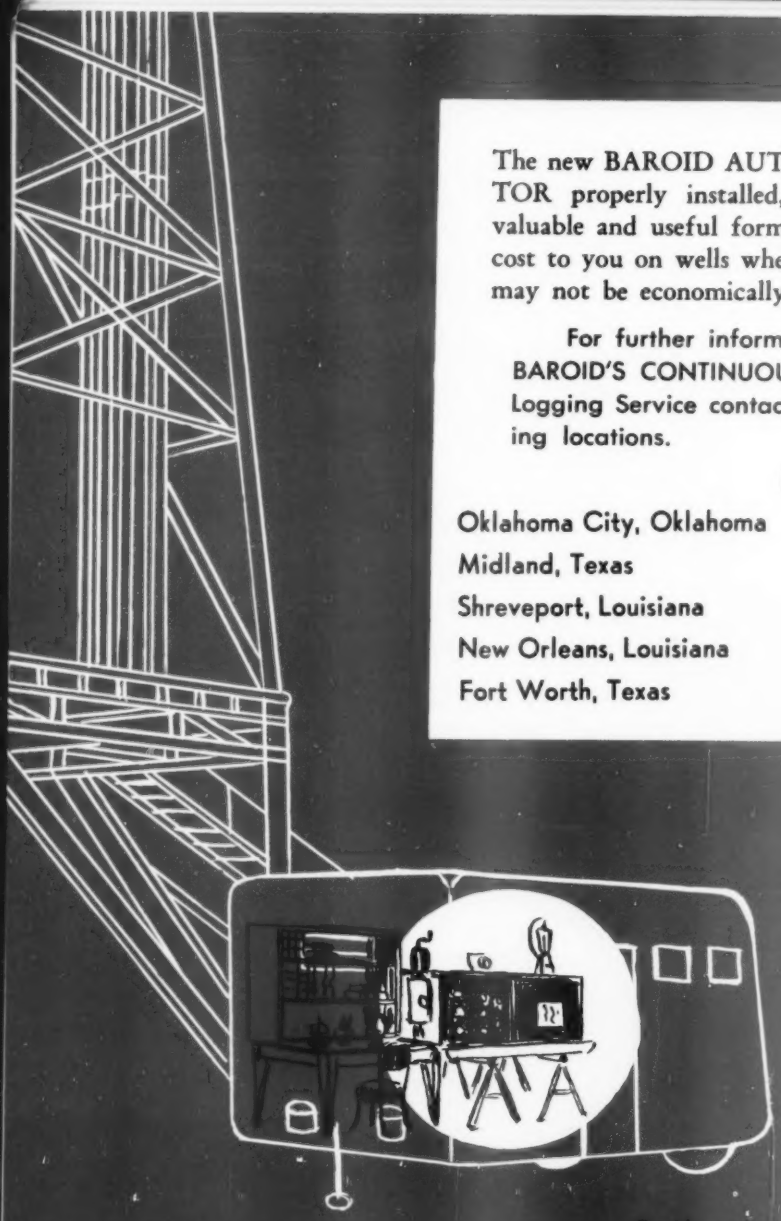
Ready for Shipment

The new BAROID AUTOMATIC RECORDING GAS DETECTOR properly installed, maintained and operated, will record valuable and useful formation hydrocarbon information at a low cost to you on wells where a complete Baroid Well Logging Unit may not be economically justified.

For further information concerning this equipment or BAROID'S CONTINUOUS MUD and CUTTINGS ANALYSIS Logging Service contact our representatives in the following locations.

Houston, Texas

Oklahoma City, Oklahoma
Midland, Texas
Shreveport, Louisiana
New Orleans, Louisiana
Fort Worth, Texas
Casper, Wyoming
Billings, Montana
Calgary, Alberta, Canada
Corpus Christi, Texas
Los Angeles, California



In Trailer

Rapid service from any of our many district offices strategically located in all oil field areas will provide technical assistance and advice on short notice in most areas. Due to our extensive Well Logging operations in the United States and Canada, Baroid's engineers and superintendents are easily and quickly available. In many cases, they will check these units without charge while on their routine duties in the district.

BAROID SALES DIVISION • NATIONAL LEAD COMPANY

2404 Danville P. O. Box 1675 Houston 1, Texas

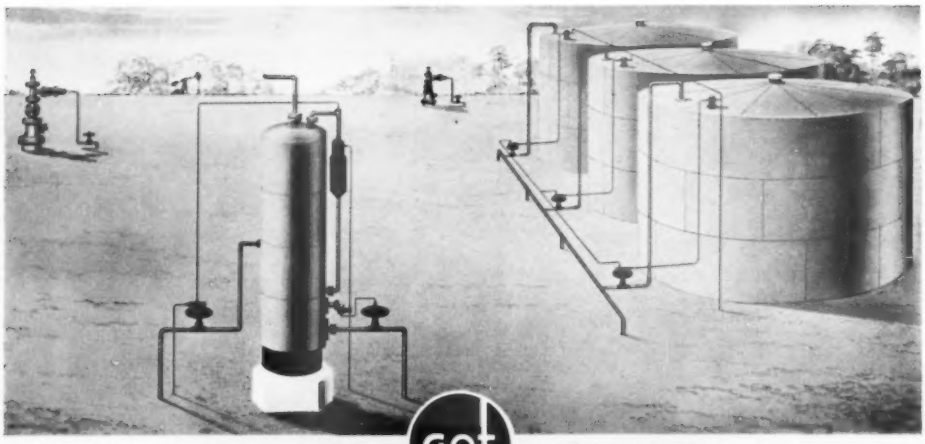
GOT retrievable gas lift valves, wire line operated circulating valves, reverse check valves and other equipment designed for permanent completion wells contain new features that offer many money-saving advantages. For full information, write for our new catalog "PERMANENT COMPLETIONS," or contact your GOT representative.

SEE THIS EQUIPMENT AT BOOTH No. 24 DURING THE ANNUAL FALL MEETING OF THE A.I.M.E. IN SAN ANTONIO, TEXAS

PERMANENT got COMPLETIONS

EQUIPMENT AND
SERVICES
TO SECURE THE
FULLEST ADVANTAGES
OF PERMANENT
WELL COMPLETIONS

Garrett Oil Tools, Inc.
P. O. BOX 2427 • LONGVIEW, TEXAS



got

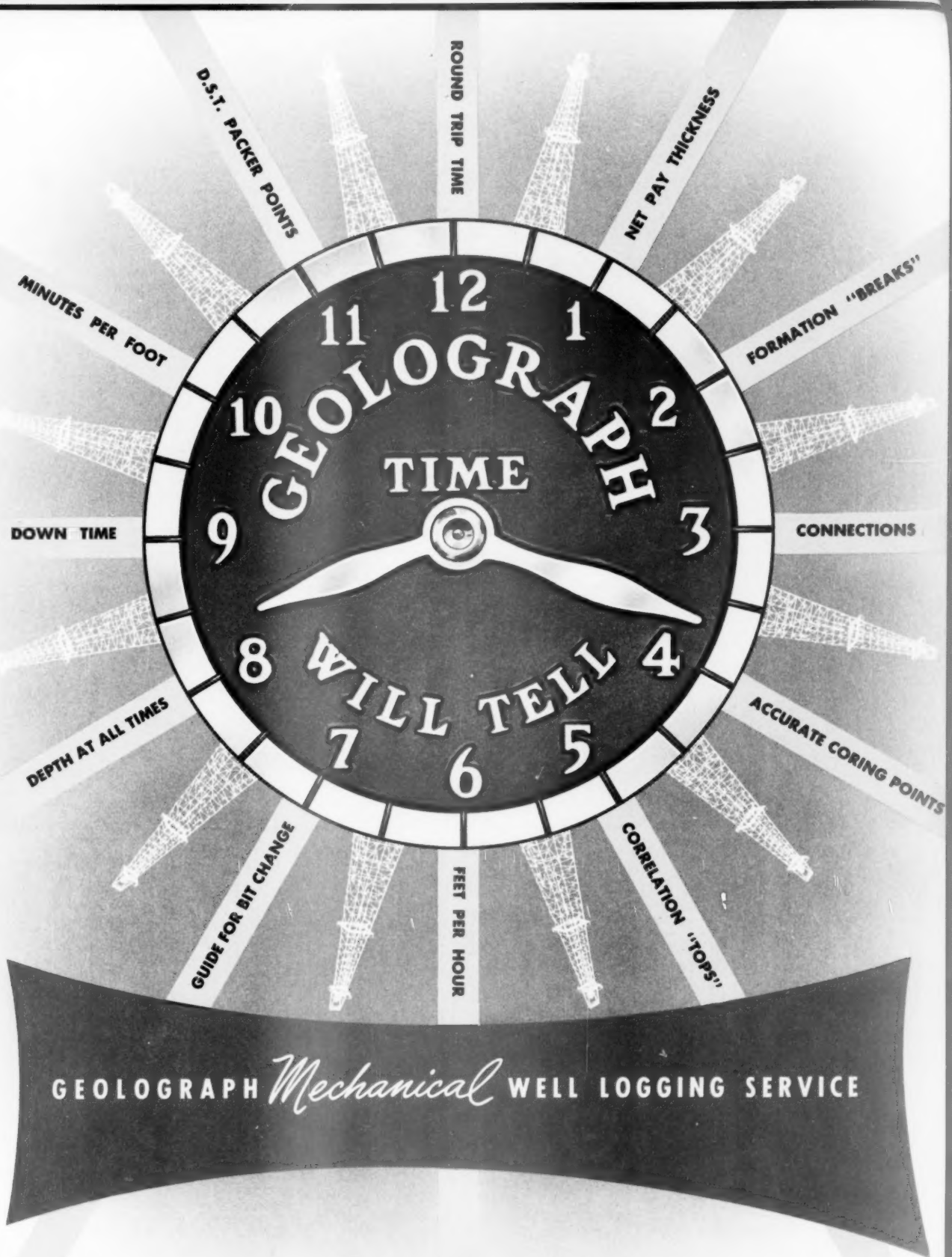
Automatic TANK SWITCHING systems

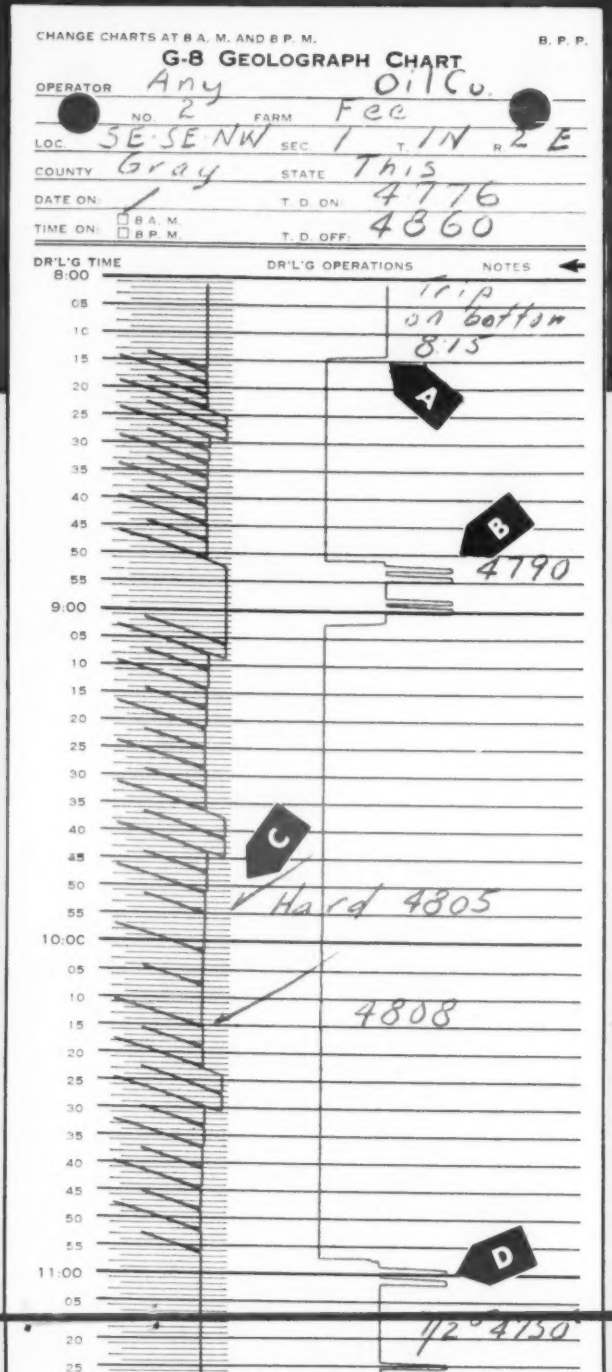
Garrett Oil Tools, Inc.

P. O. BOX 2427 • LONGVIEW, TEXAS

These pneumatic systems are adaptable to any tank battery design, and will fit into any program of lease operations. They are simple, rugged and reliable: low in cost, easy to install and maintain. For complete information, contact our Longview office or your GOT representative.

COMPONENTS OF THESE SYSTEMS WILL BE DISPLAYED IN BOOTH NO. 24 AT THE ANNUAL FALL MEETING OF THE AIME, IN SAN ANTONIO, TEXAS


ROUND TRIP TIME
NET PAY THICKNESS
FORMATION "BREAKS"
CONNECTIONS
ACCURATE CORING POINTS
CORRELATION "TOPS"
FEET PER HOUR
GUIDE FOR BIT CHANGE
DEPTH AT ALL TIMES
DOWN TIME
MINUTES PER FOOT
D.S.T. PACKER POINTS
12
1
2
3
4
5
6
7
8
9
10
11
GEOLOGRAPH
TIME
WILL TELL
GEOLOGRAPH Mechanical WELL LOGGING SERVICE



GEOLOGRAPH provides this sub-surface control while the well is drilling—

A Line in drilling operations column moves to left indicating that driller got on bottom with new bit and started drilling at 8:15.

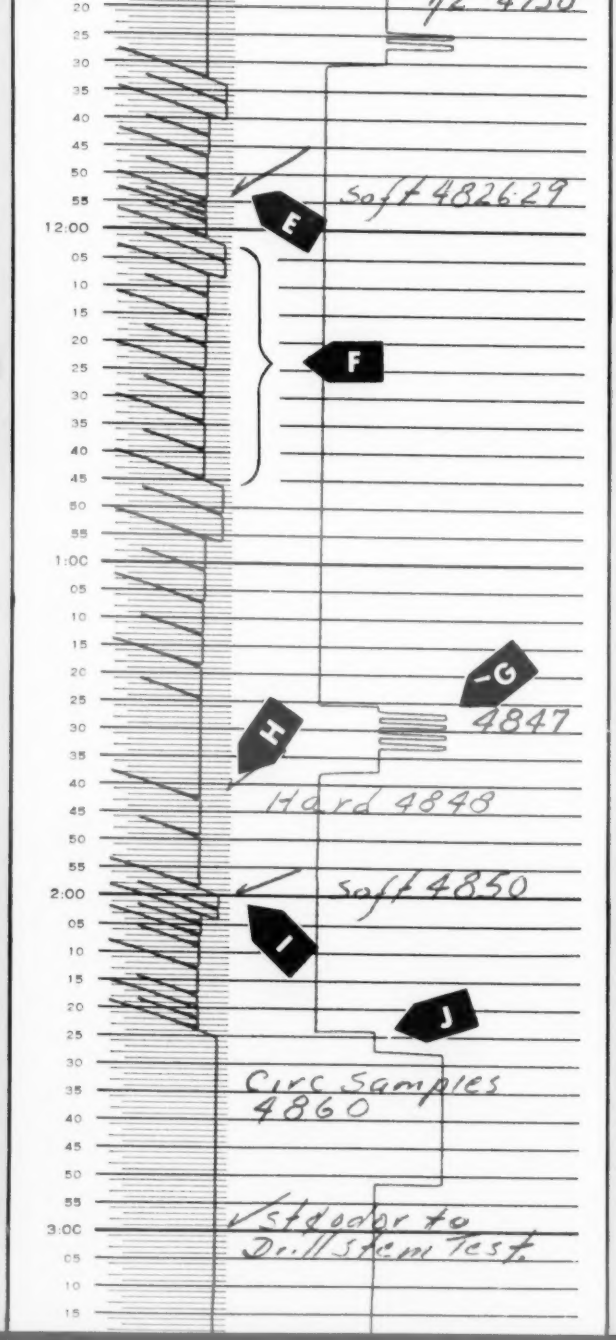
B This is the way a connection looks on the Geograph chart. The driller raised the drill pipe from bottom at 8:51, broke out the kelly, picked up a single of pipe (adding it to the drilling string), picked up the kelly and resumed drilling. This operation required 12 minutes, and the driller has written the depth of the hole, at that time, on the chart. Thus every connection is a convenient datum for determining the depth of any drilling or down-time break, either immediately above or below.

C A 3-foot hard streak was encountered at 4,805 feet, as indicated by the increased spacing of the foot marks on this time chart.

D A connection was made at 4,819 feet and a vertical test was run at this point to determine the vertical deviation of the hole. The driller has noted on the chart that the test was actually taken at 4,750 feet and the deviation was ½ degree. The vertical test and connection required 34 minutes.

E Soft bed was drilled from 4,826 to 4,829 feet. Because of the thinness of this bed no core or drill stem test was attempted.

F This section represents 10 feet of drilling. Note that every 10 feet the base line is offset for 2 feet, making a convenient marker for determining the depth of significant drilling changes.



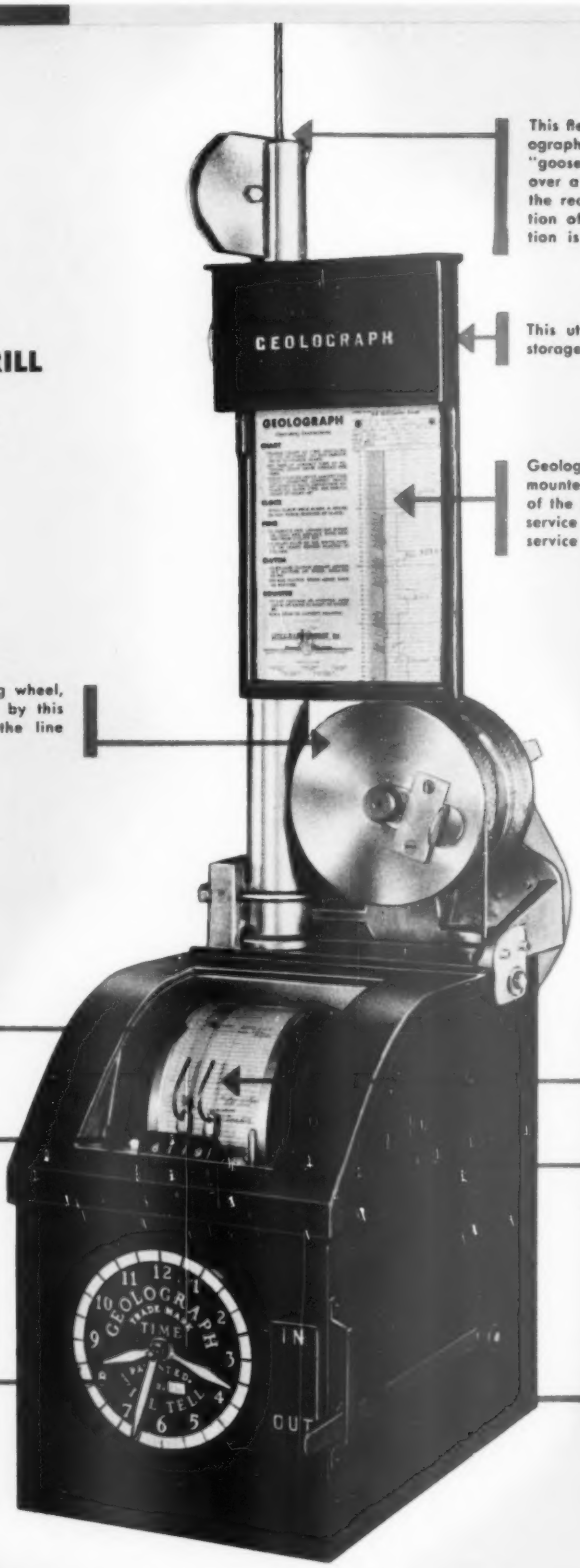
G Connection was made at 4,847 feet. Note similarity of the record at "B".

H A hard streak was encountered from 4,848 to 4,850 feet.

I At 4,850 feet the formation softened, drilling continued to 4,860 feet where the driller was given orders to cease drilling and circulate for samples.

J Circulating for samples started at 2:24 as indicated by movement of the line to the right. After circulating for 35 minutes, samples showed stain and odor, and driller was given orders to take a drill stem test.

YOU SAVE WHEN YOU LOG AS YOU DRILL WITH GEOLOGRAPH



This flexible steel cable operates the Geolograph. One end is fastened to the "gooseneck" of the rotary swivel, passes over a pulley at the crown and down into the recording instrument, where the direction of movement and extent of penetration is recorded.

This utility cabinet provides a convenient storage space for extra pens, etc.

Geolograph operating instructions are mounted under plexiglass in plain sight of the driller. This frame also contains the service card of the nearest Geolograph service point.

After passing around the metering wheel, the measuring cable is retrieved by this spring-actuated drum. It keeps the line under tension at all times.

The Geolograph Chart is easily wrapped around this chart drum. More than 3 hours of past drilling is visible at any time through the plexiglass lid and the entire record may be observed at any time by rotating chart drum. This lid is raised whenever notes, concerning observations made during drilling, are to be written on chart.

This depth meter shows the total depth at all times. When the kelly is down, the pipe tally total depth should coincide with the meter on the Geolograph. This running check on the pipe tally eliminates many errors in depth measurements.

This indicator shows — to the inch — where the bit is in relation to the foot of hole being drilled.

These long-life recording pens require no inking. They write dry, do not scratch or throw ink . . . can be replaced in a matter of seconds. Spare pens are always available in the utility cabinet.

The power clock, which turns the chart drum, is wound every 24 hours through this opening in the side plate.

The sole operation of the Geolograph consists of moving the clutch lever to the "in" position after getting on bottom, and placing it in the "out" position before leaving bottom. The Geolograph is purely mechanical and requires no electrical connection of any kind.

GEOLOGRAPH, *Mechanical Well Logging Service*

P. O. BOX 1291, OKLAHOMA CITY 1, OKLA.

Farmington, New Mexico • Liberal, Kansas • Oklahoma City, Oklahoma • Bakersfield, California • Abilene, Houston, Odessa, Lubbock and Wichita Falls, Texas • Shreveport and Baton Rouge, Louisiana Casper, Wyoming • Glendive, Montana • Sterling, Colorado • Edmonton, Alberta

THE HYDRIL SYSTEM

OF BLOWOUT PREVENTION CONTROL

with the **CARTRIDGE-TYPE PACKING UNIT**

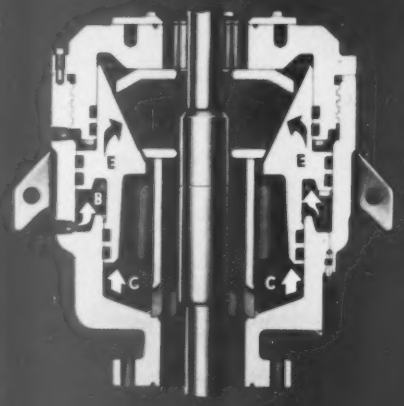
that **STRANGLES BLOWOUTS** *at the start!*

MUD IS THE PRIMARY blowout preventer. The hydrostatic weight of the mud column is the ordinary means of controlling well pressures. But when the primary blowout preventer fails because of lost circulation or inadequate mud column weight, the difference between safety and disaster is the speed with which a secure shutoff can be made.

The Hydril System of Blowout Prevention Control operates to strangle a blowout *instantly*. When danger threatens, operation of a single control lever sends hydraulic pressure from the Hydril Automatic Pump Accumulator into the closing chamber of the "GK" Blowout Preventer. Its sturdy, full-opening packing unit goes into action at once to pack off any member of the drill string or completely seal the open hole.

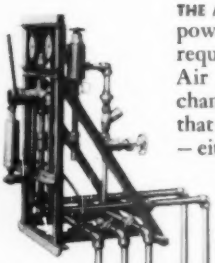
As a further safeguard, the Hydril "GK" Blowout Preventer may be closed either at the driller's control station on the derrick floor or at a safe remote control station located at the Automatic Pump Accumulator.

HYDRIL "GK"



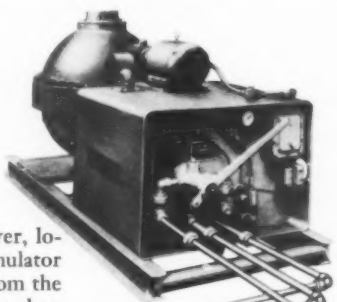
THE HYDRIL SYSTEM OF BLOWOUT PREVENTION CONTROL

Here's the Hydril-engineered system that gives quick, complete control over attempted runaway well pressures:



THE "GKH" CONTROL MANIFOLD, at right, affords instantaneous operation of the blowout preventer from the derrick floor. "A" is the four-way valve which directs fluid under pressure for opening and closing the blowout preventer. "B" is a pressure regulator valve which controls tightness of pack-off so that pipe can be rotated or tool joints stripped through the closed packing unit. "C" is a check valve to trap and hold pressure in the preventer. "D" is a globe valve which shuts off pressure so that the manifold may be easily serviced. The gages indicate regulated pressure and reserve pressure.

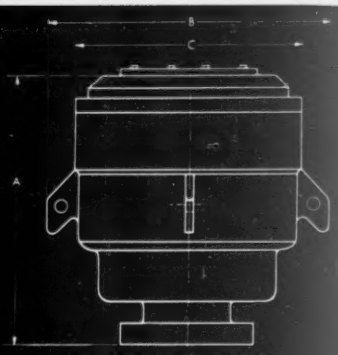
THE AUTOMATIC PUMP ACCUMULATOR is a unitized hydraulic powerplant which pumps and stores the pressurized fluid required for operation of the "GK" Blowout Preventer. Air or nitrogen is used to precharge the accumulator chamber to 750 PSI above the impervious diaphragm that separates gas and liquid. From its reservoir the liquid – either oil or water – is pumped into the accumulator chamber below the diaphragm. Motor and pump stop automatically when 1500 PSI is reached. This hydraulic pressure fluid remains in the accumulator ready for instant use in closing the preventer, and any portion withdrawn is automatically replaced.



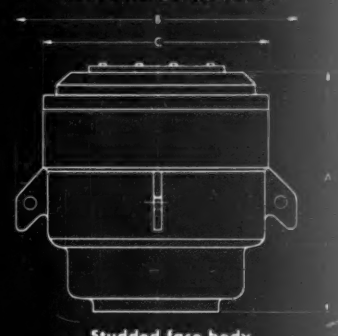
REMOTE CONTROL lever, located on the accumulator at a safe distance from the well, may be used to close the blowout preventer in an emergency.

THE "GK" BLOWOUT PREVENTER, described at right above and on page 3, may be used either singly or in multiples. Installation details may be obtained from Hydril Company or its representatives.

BLOWOUT PREVENTER



Bolted flange-type body



Studded face body

NOTE: Body is regularly furnished in either studded face or bolted flange type, API ring joint connection corresponding to size and series as shown below. Top face is regularly studded and grooved for same size and series API ring joint connection.

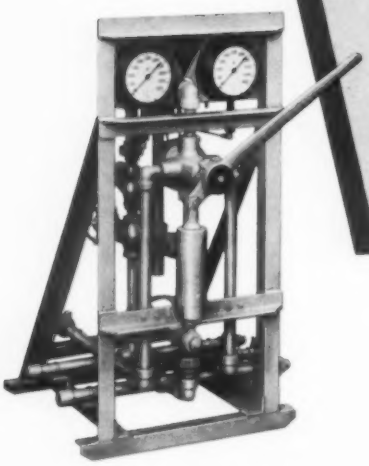
Body Size and Series	Open Bore	Pack-Off Range	Maximum Service Pressure Rating PSI	Manufacturer's Hydrostatic Test Pressure PSI	Approx. Weight, Pounds		A Bolted Flange Body	A Studded Face Body	B	C
					Flanged Body Assembly	Studded Body Assembly				
6–900	7 1/16"	7 1/16" to 0	3,000	6,000	2620	2500	32"	27 3/4"	32"	26"
6–1500	7 1/16"	7 1/16" to 0	5,000	10,000	3940	3740	36 7/8"	30 3/4"	35 3/4"	29 1/4"
8–900	8 15/16"	8 15/16" to 0	3,000	6,000	3560	3420	37 7/8"	32 3/4"	34 1/2"	28"
8–1500	8 15/16"	8 15/16" to 0	5,000	10,000	6000	5740	41 3/4"	34 3/4"	41"	34"
10–900	11"	11" to 0	3,000	6,000	5300	5140	39 3/4"	34 1/4"	40"	33 3/4"
10–1500	11"	11" to 0	5,000	10,000	8250	7800	47 3/4"	39 5/8"	44 1/4"	37 1/2"
12–900	13 5/8"	13 5/8" to 0	3,000	6,000	8580	8350	45 1/4"	39 3/8"	47 1/2"	40 1/2"
16–600	16 3/4"	16 3/4" to 0	2,000	4,000	11,500	11,220	49 1/2"	43 3/4"	53 1/4"	46 1/4"
18–600	17 7/8"	17 7/8" to 0	2,000	4,000	14,000	....	53 1/2"	.....	55 1/2"	48 1/2"

Blowout Preventer, Size	Maximum Piston Stroke In Inches	U.S. Gallons Per Inch of Piston Stroke	U.S. Gallons For Full Piston Stroke
6– 900	4 1/8	.69	2.85
6–1500	4 1/2	.86	3.86
8– 900	5 3/4	.79	4.57
8–1500	5 3/4	1.19	6.84
10– 900	6 1/8	1.21	7.43
10–1500	7 1/8	1.38	9.81
12– 900	7 1/8	1.59	11.36
16– 600	8 1/2	2.05	17.42
18– 600	9 1/4	2.28	21.09

Pipe O.D.	TYPE "GK" BLOWOUT PREVENTER SIZE								
	6–900	6–1500	8–900	8–1500	10–900	10–1500	12–900	16–600	18–600
6 5/8"	....	....	....	....	....	....	450	350	500
5 1/2"	....	....	....	....	350	350	500	400	550
4 1/2"	350	350	400	450	450	450	550	500	600
3 1/2"	400	400	450	550	550	550	600	600	650
2 7/8"	450	450	550	650	650	650	700	700	700
2 3/8"	500	500	650	750	750	750	800	800	750
1.90	600	600	750	850	850	850	900	900	850
1.66	700	700	850	950	950	950	1000	1000	950
Full Closure	1000	1000	1050	1150	1150	1150	1150	1150	1100

Pipe Size O.D.	TYPE "GK" BLOWOUT PREVENTER SIZE								
	6–900	6–1500	8–900	8–1500	10–900	10–1500	12–900	16–600	18–600
2 3/8"	4 7/8"	4 7/8"	5 3/4"	5 3/4"	6 5/8"	6 5/8"	8 1/8"	10"	10 3/4"
2 7/8"	5"	5"	5 7/8"	5 7/8"	6 3/4"	6 3/4"	8 1/4"	10 1/8"	10 7/8"
3 1/2"	5 1/8"	5 1/8"	6 1/8"	6 1/8"	6 7/8"	6 7/8"	8 3/8"	10 1/4"	11"
4 1/2"	5 5/8"	5 5/8"	6 1/2"	6 1/2"	7 1/8"	7 1/8"	8 3/4"	10 1/2"	11 1/8"
5"	5 7/8"	5 7/8"	6 3/4"	6 3/4"	7 3/8"	7 3/8"	9"	10 5/8"	11 3/8"
5 1/2"	6 1/8"	6 1/8"	7"	7"	7 5/8"	7 5/8"	9 1/4"	10 7/8"	11 5/8"
6 5/8"	....	....	7 3/8"	7 3/8"	8"	8"	9 5/8"	11 1/4"	11 7/8"
7 5/8"	....	....	....	....	8 1/2"	8 1/2"	10"	11 3/4"	12 1/4"
8 5/8"	....	....	....	....	9"	9"	10 3/8"	12 1/4"	12 5/8"
9 5/8"	....	....	....	....	....	....	10 7/8"	12 3/4"	13"
10 3/4"	....	....	....	....	....	....	11 1/2"	13 1/4"	13 3/4"
13 3/8"	....	....	....	....	....	....	.....	.....	14 3/4"

just ONE LEVER to move when a blowout threatens!



"GKH" Control Manifold

In an emergency there's no time to start balky motors and pumps, or to figure out which valves to open and close in a complicated manifold. Hydril controls – the answer to the need for swift action – assure instant and positive pack-off with always-ready pressure from the accumulator. The Hydril Type "GKH" Control Manifold is available in unitized multiples where more than one Preventer is used.

Two-Station Control Manifold

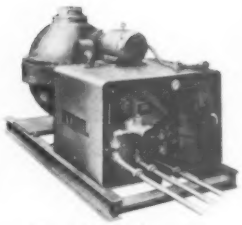
Three-Station Control Manifold

hydraulic power instantly available!

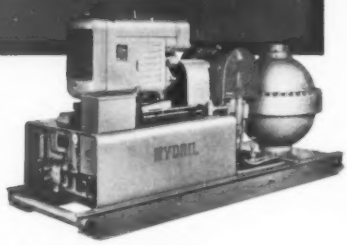
Hydril Automatic Pump Accumulator Units provide a continuous supply of high-pressure fluid for instantly closing pressure-operated Hydril Blowout Prevention Control Equipment. Available in 40- or 80-gallon capacities, powered by electric motors or gasoline engines to suit any field conditions.

For further information about the Hydril System of Blowout Prevention Control, write or wire Hydril Company, or contact your nearest Hydril representative.

Also, ask about the *new* Hydril "MSP-2000" Blowout Preventer.



Automatic Pump Accumulator
Model HB-17-80
with Remote Control Valve



Automatic Pump Accumulator
Model GE-75-80

Model No.	Fluid Capacity. Hydro-Pneum. Accum.-Gals.	Total Reservoir Cap.-Gals.	Pump Capacity. gpm	Charging Time, Minutes	Motive Power	Dimensions			Approx. Net Weight Lbs.
						L	W	H	
HB-17-40	20	75	1.7	11.7	3 HP. AC Electric Motor	86¼"	36"	52¼"	2670
DCEPM-17-40	20	75	1.7	11.7	3 HP. DC Electric Motor	86¼"	36"	52¼"	2900
GE-17-40	20	75	1.7	11.7	1 Cyl. 4.2 HP. 1800 RPM API Rated Gasoline Engine	86¼"	36"	60"	3050
HB-17-80	40	140	1.7	23.4	3 HP. AC Electric Motor	99¼"	42"	51¼"	4015
DCEPM-17-80	40	140	1.7	23.4	3 HP. DC Electric Motor	99¼"	42"	56¼"	4250
GE-17-80	40	140	1.7	23.4	1 Cyl. 4.2 HP. 1800 RPM API Rated Gasoline Engine	99¼"	42"	64"	4275
HB-75-80	40	190	7.5	5.3	10 HP. AC Electric Motor	133½"	42"	53¼"	5485
GE-75-80	40	190	7.5	5.3	4 Cyl. 18 HP. 1800 RPM API Rated Gasoline Engine	133½"	42"	64"	5645
HB-150-80	40	190	15	2.6	25 HP. AC Electric Motor	133½"	42"	55¼"	6495
GE-150-80	40	190	15	2.6	6 Cyl. 35.1 HP. 1800 RPM API Rated Gasoline Engine	133½"	42"	76¾"	6375

HYDRIL COMPANY

714 West Olympic Blvd., Los Angeles 15, Calif.

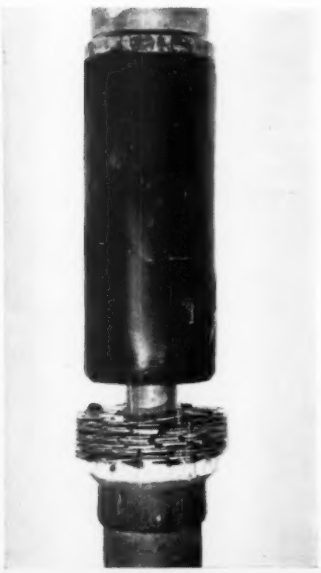
Factories: Los Angeles; Houston, Texas; Youngstown, Ohio; Rochester, Pa.

SALES OFFICES: California: Bakersfield, Los Angeles, Ventura ... **Louisiana:** Harvey, New Iberia ... **Ohio:** Youngstown ... **Oklahoma:** Tulsa ... **Pennsylvania:** Rochester ... **Texas:** Corpus Christi, Dallas, Houston, Midland, Odessa ... **Wyoming:** Casper ... **Canada:** Calgary, Edmonton

RSBB 323 12.5M 8-54 PRINTED IN U.S.

AVAILABLE JOHNSTON SAYS:

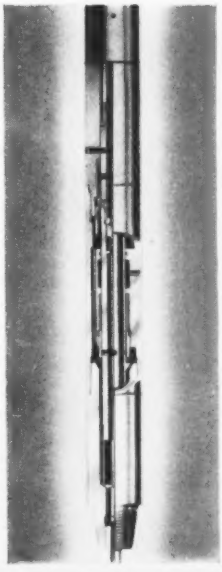
THE 100% HYDRAULIC TESTER WITH THE BT OPEN HOLE PACKER



This New, Proven Combination of the Johnston Hydraulic Tester, teamed with the Type **BT** Extrusion-Proof Open Hole Packer, provides the drilling and producing industries with the most reliable drill stem testing method ever developed!

The Type B Hydraulic Tester is a compact, rugged unit that permits a controlled release of pressure in the test zone. Prevents the usual shock to formation and equipment that occurs with sudden release of pressure.

The Type BT Packer positively eliminates extrusion or flow of rubber. Since the entire volume is held in the pack-off zone, its possible to use a smaller diameter packing element for more clearance, more positive pack-off and easy removal from packer seat.



HERES THE STORY ON TH' JOHNSTON HYDRAULIC TESTER. AN' HOW IT WORKS:

The Johnston Hydraulic Tester with staged opening provides these four important advantages:

- **Less plugging of perforated anchor, chokes and testing ports.**
- **Reduced damage to wall of hole.**
- **Less shock to drill pipe, packer and instruments.**
- **Reduced amount of fluid cushion in many instances.**

This 100% Hydraulically Operated Tester is just what its name implies—a simple hydraulic pump made up of two chambers; the upper chamber containing hydraulic fluid. A metering device between upper and lower chambers controls the transfer of fluid during the operating cycle.

The Lower Chamber Contains a floating piston, while the piston in the upper chamber is fixed to the mandril. The area of the two pistons is equal, so the hydrostatic pressure in the well has no influence on the operation of the tool.

The Only Factors Influencing The Operation are the applied weight of the drill pipe and the size of the orifice in the metering device.

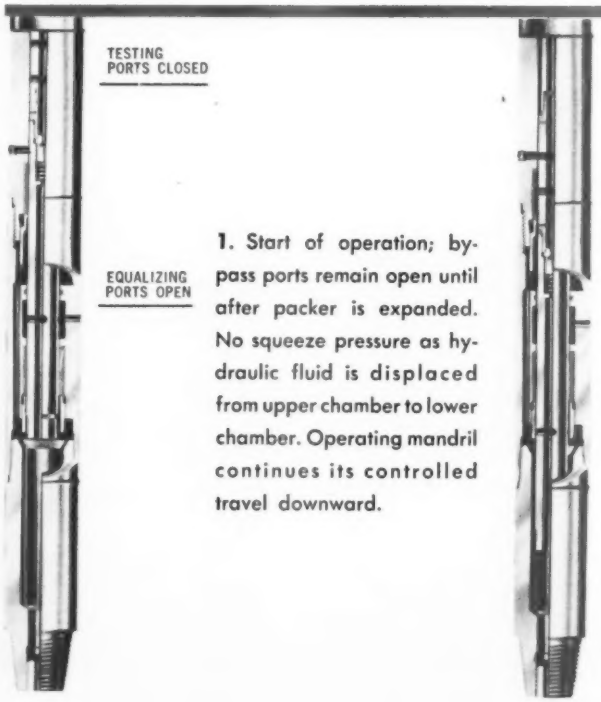
OPERATION:

Weight of The Drill Pipe causes the piston in the upper chamber to exert force on the hydraulic fluid, forcing it through the metering device. The mandril travels downward as the process continues. The by-pass ports are closed as they enter the lower packing (Fig. 1).

The Bleed-Off Port Then Moves out of the upper packer (Fig. 2) permitting the slow release of pressure below the packer.

The Final Cycle in the opening operation is the exposure of the main testing ports (Fig. 3).

The Orifice in The Metering Device is easily changed on the rig floor prior to starting into the hole. This allows a wide choice in the selection of the time interval needed for opening.



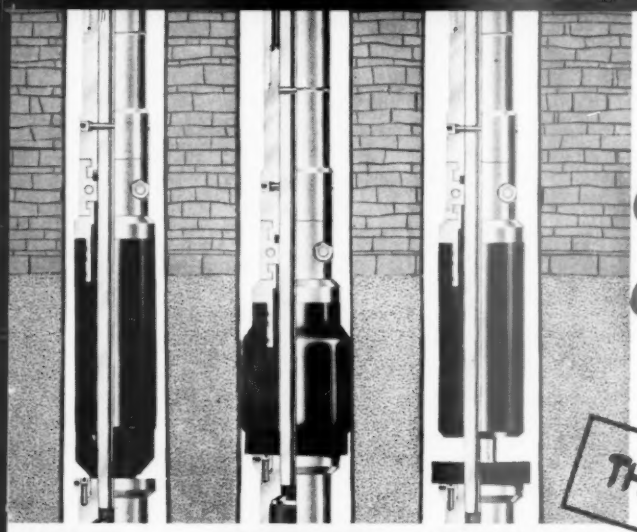
1. Start of operation; by-pass ports remain open until after packer is expanded. No squeeze pressure as hydraulic fluid is displaced from upper chamber to lower chamber. Operating mandril continues its controlled travel downward.

left

2. The by-pass ports are closed. The small bleed-off ports are exposed and pressure in the test zone is slowly released. The bleed-off ports remain active for 50 to 90 seconds, depending upon the predetermined operating time cycle.

right

3. The production ports are now open and the maximum pressure differential is applied to the test zone.



GOING IN

This diagram of the running-in position shows how you now get up to 4 times the clearence possible with conventional packers.

PACKED OFF

In the pack-off position, the metal petal cups form a laminated support for the rubber. It is contained in the pack-off zone and completely eliminates extrusion or cold flow.

COMING OUT

Note the condition of the rubber element and the flattened plates. If a bridge or tight spot is encountered, the metal petal cups bend smoothly down over the aluminum support shoe.

AN' HERE'S TH' COMPLETE IN-FO-MAY-SHUN ON THE BOB TAIL PACKER-

THIS - NOT THIS

For comparison, a photograph showing the effects of extrusion or cold flow.

The Most Difficult Problems in the field of formation testing have been easily solved with the development of the Bob Tail Packer. By necessity, this tool is of a diameter that allows running into the hole with maximum clearance . . . permits getting by tight places in the hole and does not damage the wall of the hole.

Upon Reaching The Pack-Off Point, the packer must be able to increase in diameter to effect a seal against the wall of the well bore. This seal must be made against any formation and be able to support a load of several thousands of pounds per square inch.

After The Test Period, the packing element must be returned to its original elongated position to permit removal of the packer from the hole without dragging on the wall of the hole.

TESTING PORTS OPEN

EQUALIZING PORTS CLOSED

SEE BACK PAGE FOR MORE INFORMATION—

DATA ON RUBBER ELEMENT AND METAL PETAL CUP

Hole Size	Packer Element O.D.	Cup Diameter (Cupped)	Cup Diameter (Flat)
5¾—6¼"	5"	4¾"	5⅝"
6⅜—6¾"	5¾"	5-3/16"	6¼"
6⅞ x 7¼"	5¾"	5-7/16"	6¾"
7½ x 7⅝"	6½"	6⅛"	7⅜"
7¾ x 8¼"	6½"	6-5/16"	7⅝"
8⅜—8⅝"	7¼"	6-11/16"	8¼"
8¾—9"	7¼"	6⅞"	8½"
9⅛—9½"	8"	7-3/16"	9"
9⅝—10"	8"	7½"	9½"

JOHNSTON TESTERS

first in drill stem testing

HOUSTON, TEXAS

LOS ANGELES, CALIF. • CALGARY, CAN.

FORMATION AND CASING TESTING — JOHNSTON

KINZBACH TOOL CO INC

engineering report

MODEL 112 AUTOMATIC RELIEF VALVE
for Mud Systems and Other High Pressure Hydraulic Applications

This valve is designed to provide instantaneous relief from pressure surges in hydraulic systems, with fast, automatic resetting as soon as the cause of the overload is removed.

Fully automatic action is accomplished through the use of two unique combinations of elements restraining the valve piston movement. (1) The basic combination consists of four compression springs located radially about the valve piston, and inclined at a predetermined angle to its axis. Resulting spring thrust, resisting valve piston movement, decreases progressively as the valve piston moves from closed to open position. Conversely, the thrust increases as the valve piston moves from open to closed position. This characteristic is illustrated in the curve of Fig. B labeled "Spring Resistance." (2) Superimposed on this spring resistance is the resistance of a slitted Detention Sleeve and a Wedge, mounted on the valve piston (see Fig. C). An internal annular shoulder of the Detention Sleeve is maintained in contact with a beveled surface of the Wedge when the valve is in closed position. The Wedge must expand the Detention Sleeve to permit valve piston movement into open position. The resistance of this combination is proportional to the difference in diameter of these elements, and is adjustable by changing the Wedge diameter. This provides a simple, easy, and accurate means of adjusting valve pop pressure within the range of the combination. The resistance of this combination to valve piston movement from closed position is dropped immediately with the initial piston movement, as illustrated in the section of Fig. B labeled "Resistance of Detention Sleeve and Wedge."

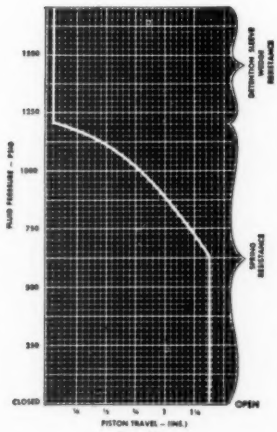


Fig. B

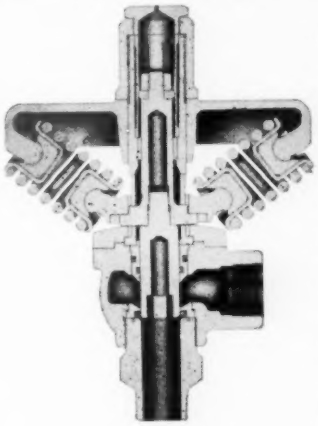


Fig. C
Closed

The cumulative effect of these combinations on the operating characteristics of the Relief Valve is illustrated in Fig. B. At a pressure of 1750 p.s.i. the combined resistance of the springs and Wedge-Sleeve combination is overcome and the valve starts opening. After an initial increment of valve piston movement the restraining force of the Spring-Wedge combination is removed and only the 1200 p.s.i. spring resistance remains. This resistance decreases to the value indicated for full open position of the valve piston. In operation, due to compressibility of the mud, surge chambers, air in the system, and pump surges, this movement is very rapid and a volume of fluid in excess of average pump discharge is bypassed usually, dropping the pressure in the system to a value below the spring thrust on the valve piston. Consequently the valve piston is rapidly forced into its closed position by the increasing thrust of the spring elements before the system pressure can be rebuilt enough to arrest its movement. During periods of excessive circulating pressures, the valve either repeats this cycle of rapid opening and closing or remains open until the obstruction is removed or the pump speed is reduced. The pump and other elements of the circulating system are protected from excessive overloads at all times. When using as a mud pump relief valve and momentary circulation blocks occur, it is not necessary to shut down pumps for relief valve resetting. The movement of the fluid stream may not be materially affected, thus preventing a period of lost circulation and the danger of stuck drill pipe which often occurs during such a period.

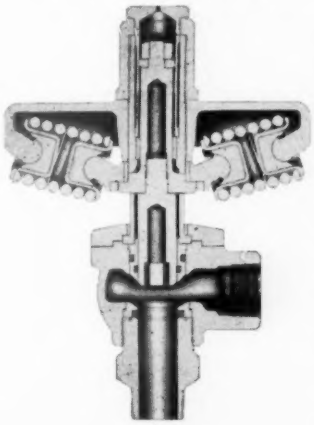


Fig. D
Open

KINZBACH TOOL CO INC

Engineering Report

KINZBACH MODEL 112 AUTOMATIC PRESSURE RELIEF VALVE

The following outline has been developed from service data accumulated in the operation of Kinzbach Model 112 Automatic Mud Pump Relief Valves:

1. POWER END PROTECTION. Mud pumps are rugged pieces of equipment. However, all design is based on normally anticipated peak loads. Due to the wide range of field operating conditions encountered, many of which are indeterminate or unpredictable, protective equipment of known characteristics is essential.

The Kinzbach Model 112 Pressure Relief Valve can be field-set within a predetermined range of pop pressures and is accurate throughout this range.

2. HYDRAULIC SYSTEM PROTECTION. Depending on the effectiveness of pulsation dampening devices and the development of harmonic conditions, pressure surges of tremendous magnitude can be developed in the hydraulic system. These surges propagate very rapidly and may be considered as shock loading with well-known hazards for all subjected fittings. (See chart at right.)

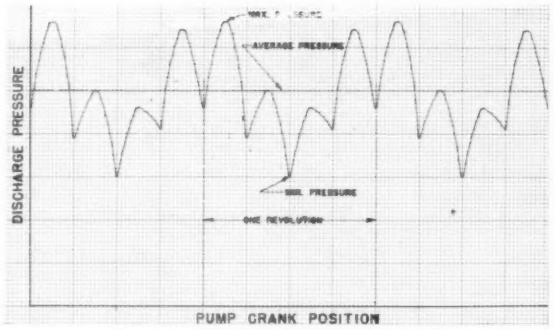
The Kinzbach Model 112 Pressure Relief Valve will discharge these surge peaks at a known pressure, maintaining a maximum system pressure at that for which it has been set.

3. MAINTENANCE OF CIRCULATION. When drilling with a heavy load of cuttings suspended in the fluid column, any interruption of circulation may permit their settling in the annulus and sticking the drill pipe.

Use of the Kinzbach Model 112 Pressure Relief Valve minimizes this hazard since it will reset automatically, and circulation blocks of a momentary nature, such as occasioned by spudding into a soft bottom or improper operation of a mud line valve, do not necessitate a pump shut-down for valve resetting.

4. BUCKING GAS SURGES. In a recent operation, the blow-out preventer had been tested hydrostatically to 1700 p.s.i., at which point leakage occurred. Since no pressures of this magnitude were anticipated, it was installed on the well. Kinzbach Model 112 Mud Pump Relief Valves were set at 1500 p.s.i.

Subsequently, a gas pocket was encountered, and heads of gas pressure in the drill pipe exceeded total pressure head of the drilling mud. As this occurred, the Relief Valve automatically discharged the peak surges, and pumps were kept running until sufficient mud materials were added to effect control, thus avoiding a blow-out.



5. CASING PROTECTION. Circulating pressures during cementing and other critical operations must be under control to avoid casing failure.

Kinzbach Model 112 Pressure Relief Valves insure the operation against pressures in excess of their predetermined setting. Cement plugs may be pumped more quickly and safely with this assurance.

6. HOLE PROTECTION. Down-hole pressure is the resultant of mud weight, annulus dimension, drill pipe size, and circulating volume. In general, the circulating volume is the variable most susceptible to deviation from prescribed procedure. Formation break-down and other hazards arise from these excessive pressures.

The Kinzbach Model 112 Mud Pump Relief Valve, with its accurate, predetermined range of pressure relief, insures that planned procedures will be followed.

Ask a Kinzbach engineer to show you all the technical data on these valves. They are available in the following sizes and pressure ranges:

TYPE	SIZE	PRESSURE RANGE
E	2″	750 — 2750
F	2″	750 — 2750
EIB	2″	up to 1500 p.s.i.
E-4	2″	1500 — 4300
E-6	2″	2200 — 6500
EI5	2″	3700 — 16,500
FE	3″	500 — 3750

KINZBACH TOOL CO., INC.

2411 Summer St., P. O. Box 277, Houston 1, Texas

Here's the story in a NUTSHELL...

O·C·T "C·19" CASING HEADS

nipple up faster, easier
eliminate open hole hazards
save hours of rig time

Regardless of how or when you decide to install the O-C-T "C-19" Casing Hanger . . . before cementing, after cementing, through preventers, or at any time in case of stuck pipe . . . you can improve the safety of your completion operations and save hours of expensive rig time due to the flexible, simplified O-C-T installation procedure.

Yes, we guarantee that the "C-19" can be set and nippled up faster than any other casing head under the installation procedure of your choice. Let us show you on your next well. Ask your O-C-T Representative today for details of this guaranteed performance!

O-C-T Products, dependable and available through more than 700 supply store locations.

WRITE FOR COMPLETE INFORMATION

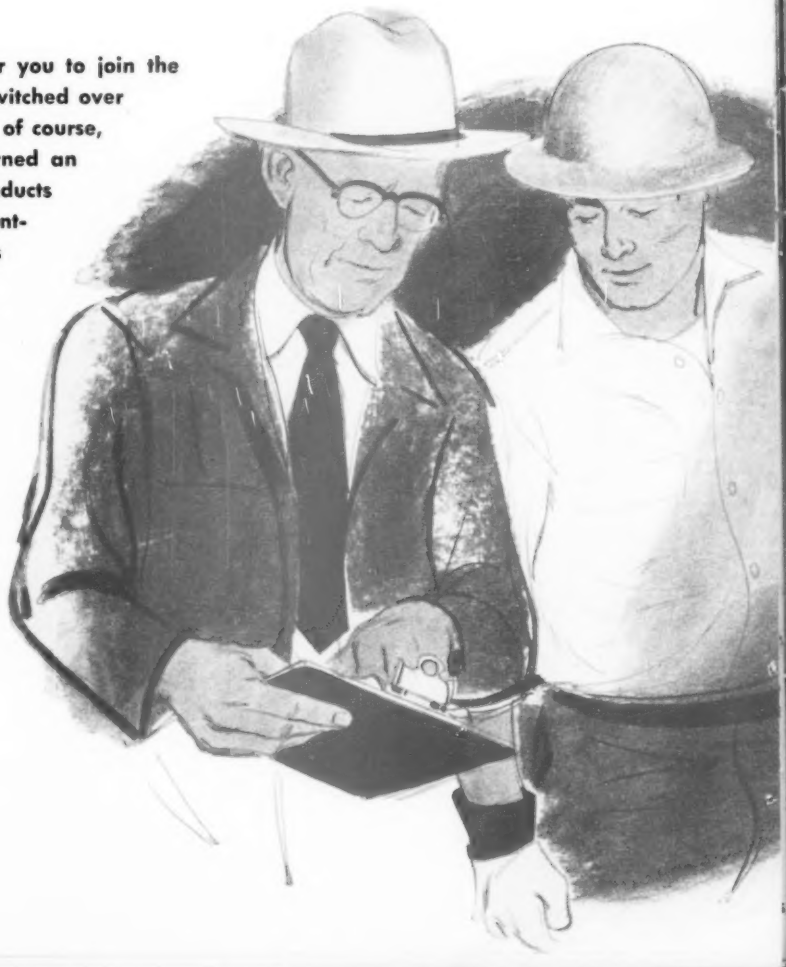
Oil Center Tool Co.
P. O. Box 3091, Houston, Texas

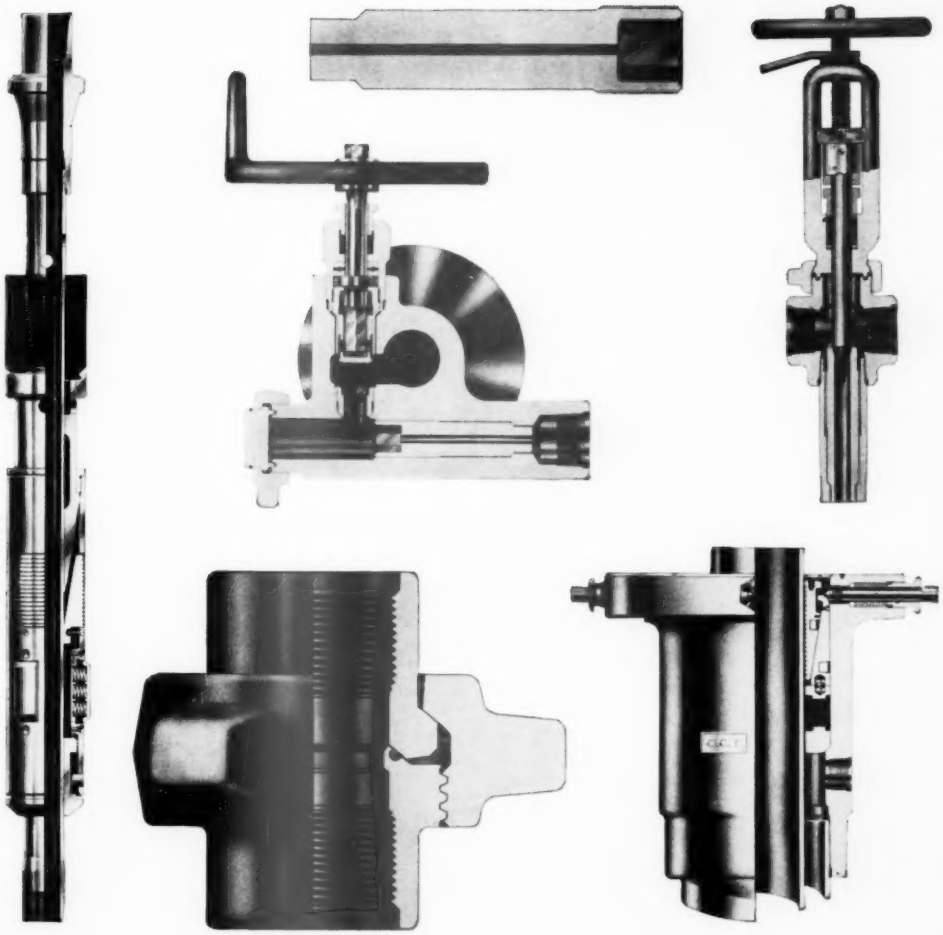
Export Representatives:
Sterling Areas — Le Grand, Sutcliff & Gell, Ltd., Southall, Middlesex, England. Address Export Inquiries for All Other Countries to P. O. Box 3091 Houston 1, Texas.

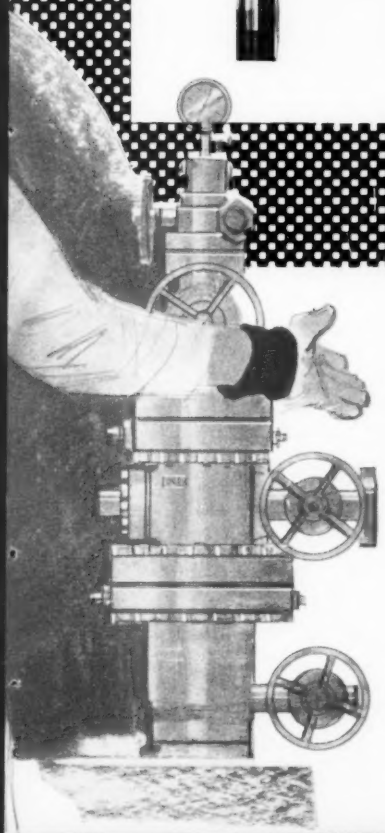
ECONOMY
SERVICE
SAFETY

It's the extra value that makes O-C-T stand out

There are many good reasons for you to join the growing list of oil operators who have switched over to O-C-T Products. The best reason of all, of course, is the fact that O-C-T Products have earned an industry-wide reputation as the finest products money can buy. This record-for-consistent-performance has been marked up in wells of all depths and pressures. Isn't it logical then that you should learn about the added strength, safety, convenience and flexibility provided by dependable O-C-T products? Let us furnish complete information and quotations on your next well. No obligation. Write today or talk to your O-C-T Representative.







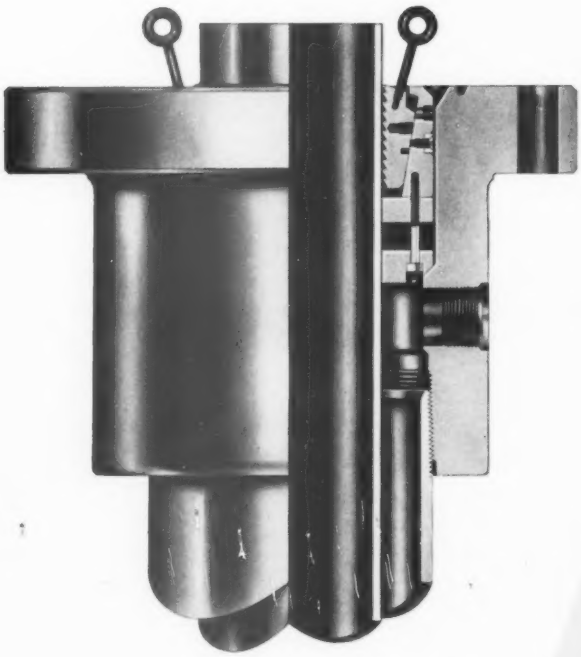
Oil Center Tool Co.

P. O. BOX 3091, HOUSTON, TEXAS

Export Representatives: Sterling Areas — Le Grand, Sutcliff & Gell, Ltd., Rochester, Kent, England. Address Export Inquiries for All Other Countries to P. O. Box 3091, Houston, Texas.

here's the new MIDDLEWEIGHT champion

Ever since O-C-T pioneered the first deep well casing head that provided casing seal and suspension before blowout preventers were removed, we have recognized the need for this same safe, simplified type installation for a medium priced — medium duty casing head. Now, O-C-T research and study of casing head flexibility and safety have resulted in the introduction of this new O-C-T "C-20" Casing Head for medium depth wells. Check the features, advantages, and safety this new O-C-T head brings to the field . . . then write for the C-20 Brochure containing Engineering Nomograph for Calibrating Casing Loads and Pressures . . . Or ask your O-C-T Representative for details. Available through more than 700 supply store locations.



O-C-T
C-20
CASING
HEADS

THE FIRST AND ONLY QUICK-SETTING, POSITIVE-SEALING WELL HEADS DESIGNED ESPECIALLY TO ELIMINATE OPEN HOLE HAZARDS IN MEDIUM DEPTH WELLS.

1. Seals and suspends casing before blowout preventers are removed.
2. Saves hours of costly rig time — simplifies installation.
3. Sealing element, slip bowl and slips are assembled at the O-C-T plant as a single unit that may be wrapped quickly around the casing, latched and dropped into place from the derrick floor.
4. It employs a resilient seal ring which provides an effective seal for the life of the well in any climate.

Oil Center Tool Co. P. O. Box 3091 Houston, Texas

Export Representatives: Sterling Areas — Le Grand, Sutcliff & Gell, Ltd., Rochester, Kent, England. Address Export Inquiries for All Other Countries to P. O. Box 3091, Houston 1, Texas

radioactivity logging

by Schlumberger

The Importance of Radioactive Logs to the Oil Industry

Schlumberger's modern Gamma Ray and Neutron logs supply information which makes them important tools for oil exploration and production.

1. They make available a logging method which measures formation characteristics behind the casing.

2. They can be recorded in empty holes and oil base muds as well as in normal drilling fluids.

3. They determine lithology and can often be used quantitatively for the calculation of reservoir porosity.

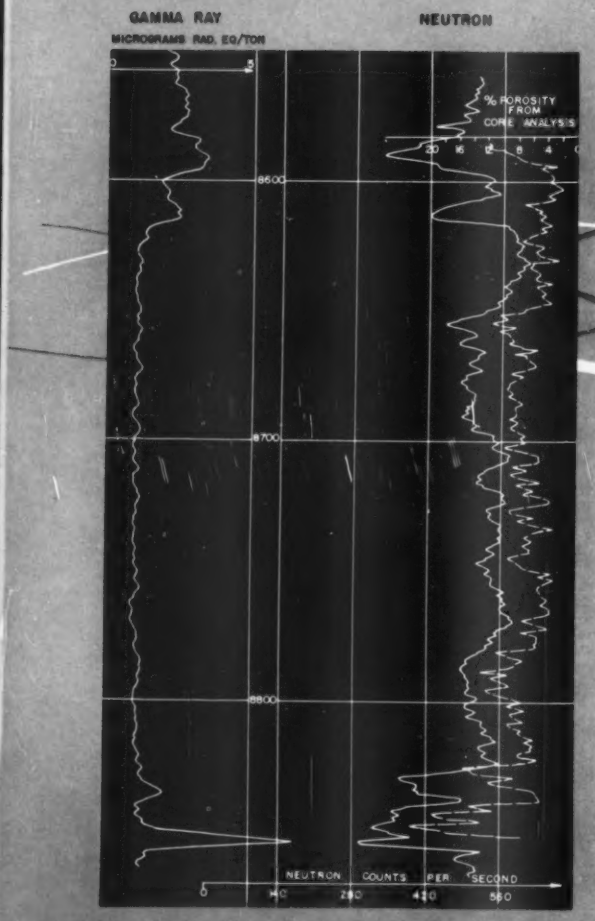


Fig. 1. Gamma Ray-Neutron Combination. Note the excellent agreement of the plotted core analysis to the Neutron curve.

Relative Radioactivity of Rocks

The Schlumberger

gamma ray log

The Gamma Ray instrument measures the variation of natural radioactivity emitted from the formations penetrated by the drill. Since shales are generally more radioactive than sands or limestones, the log variations often correspond to lithological changes in a manner similar to the S. P. curve of the electrical log. Therefore, the Gamma Ray log is a measurement of a natural phenomenon by which lithology, formation depth and formation thickness may be determined.

USE IN SALTY MUD

In areas where wells are drilled with salty mud, the character of the electrical log is reduced. In such areas, the Gamma Ray log is often used as a substitute for the S. P. log, usually in combination with the Neutron log, MicroLog, Microlaterolog, or with focused logs which are little affected by the saline drilling fluid.

USE IN EMPTY HOLES OR OIL BASE MUDS

It has become normal practice to run the Gamma Ray log in oil base muds or empty holes, usually in combination with the Neutron log and the Induction log. The Gamma Ray log determines lithology, the Neutron log locates the porous zones and the Induction log indicates formation resistivity.

USE IN OLD FIELDS

Gamma Ray logs furnish a means of correlation between cased holes in which no electrical logs were run. Thus, formations known to be productive, either from the electrical log or production history of other wells, can be properly perforated for a satisfactory workover completion.

USE IN PERFORATING DEPTH CONTROL

Because a Gamma Ray log can be recorded in a cased hole, it offers an excellent method of depth control for perforating operations. In areas where Gamma Ray-S. P. correlations are good, a Gamma Ray curve is recorded simultaneously with a Schlumberger casing collar log. The depth of the casing collars are then defined in terms of electrical log depths by direct correlation with the S. P. (open hole) curve. Then, the well is perforated directly from electrical log depths by relocating the collars near the shooting depth with the perforator attached. If Gamma Ray-S. P. correlations are not reliable, an open hole GR-SP combination is run. This directly ties the Gamma Ray log depths to those of the electrical log. After pipe is set a second Gamma Ray log is run which is correlated with the open hole Gamma Ray and hence the electrical log. A collar log is run simultaneously with the second Gamma Ray log and perforating depth control then achieved as outlined above.

These depth control methods have proven very effective, particularly in the case of thin producing horizons.

THE SCHLUMBERGER INSTRUMENT

Schlumberger Gamma Ray instruments are built in three diameters — 3⅜, 2⅝, and 1⅜ inches. The small 1⅜" instrument has made it possible for the oil operator to obtain the advantages of Gamma Ray Logging in permanent-type well completions. It will readily pass through two-inch tubing.

The instruments are presently being built with two types of counters: the Geiger-Muller Counter, which has been standard for a number of years, and the more recently adapted scintillation counter. Both have inherent advantages, and both can be run at recording speeds which minimize rig time.

THE CALIBRATION OF SCHLUMBERGER GAMMA RAY LOGS

Natural gamma rays in the earth originate directly or indirectly from three radioactive elements: uranium, thorium and potassium. Schlumberger Radioactive well logging equipment records the combined gamma ray activity of these elements in each formation. In order to calibrate the log quantitatively, Schlumberger has chosen a calibration unit based on the equivalent radium concentration — radium being a member of the uranium decay series. This Schlumberger unit is defined as micrograms of radium-equivalent per ton of formation. The range most frequently observed in the bore hole is from 1 to 20 of such units (μg Ra-eq/ton) and full scale deflection on the Schlumberger Gamma Ray log is between 5 and 20 μg Ra-eq/ton. This unit is now standard and appears on all Schlumberger logs.

The response of the gamma ray detector for a given formation is not dependent on formation radioactivity alone. It also varies with the size of the bore hole, weight of the mud, thickness of casing, etc. Therefore, just as is the case with resistivity curves, the Gamma Ray curve must be corrected to read true formation radioactivity. Schlumberger has done a large amount of experimental work on such corrections and has published departure curves which take into account the most common variables. Figure 2 shows how the variables can affect a Gamma Ray curve. By using the departure curves, together with some knowledge of the variables encountered in a specific condition, it is often possible to correct a Gamma Ray curve so that it can be used quantitatively. This is of particular importance in estimating the shale content in shaly sands. Such information is valuable when used with the Neutron log, for the determination of shaly sand porosities.

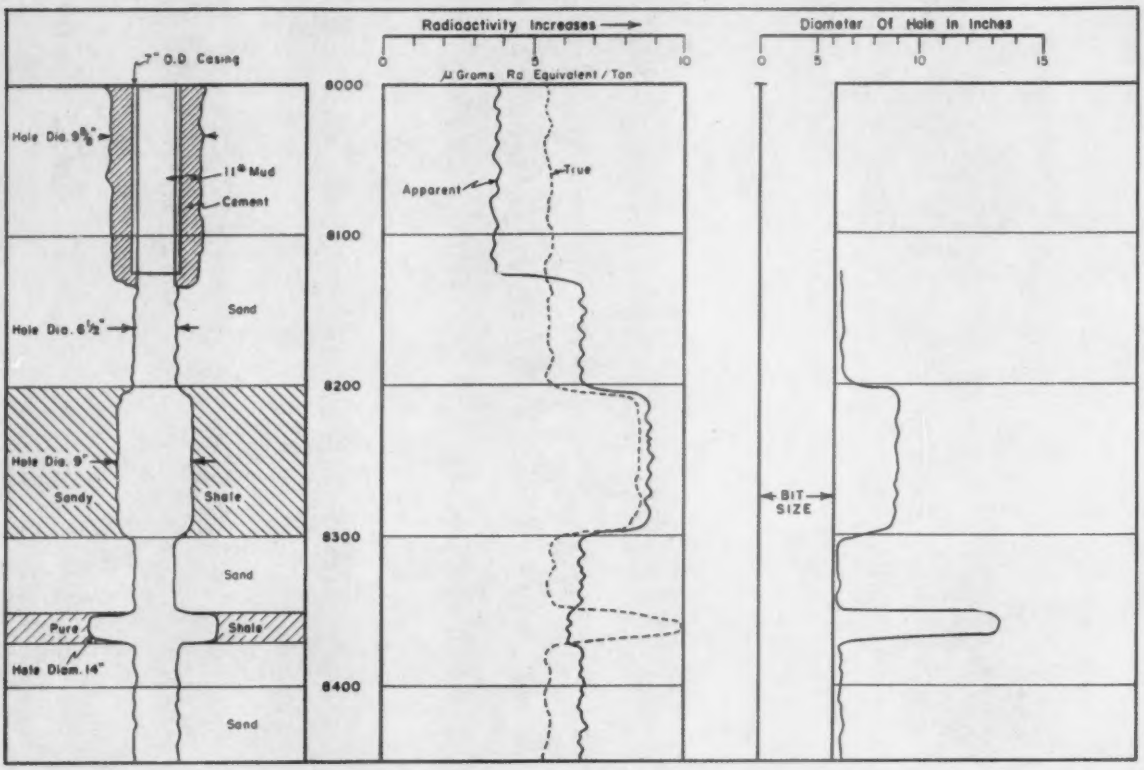


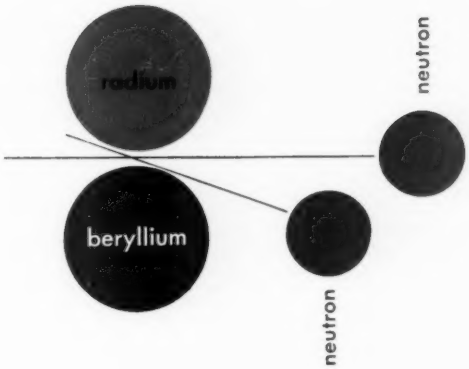
FIG.2. Effect of casing, cement, and hole size on apparent radioactivity.

Advantages of the Schlumberger Gamma Ray Instrument

1. It operates satisfactorily under the following bore-hole conditions:
   a. Normal drilling mud.
   b. Salty mud.
   c. Oil-base mud.
   d. Empty holes.
   e. Cased holes.
2. It is built in diameters to fit normal casing or tubing sizes: 3⅜", 2⅜", and 1 11/16".
3. It is unaffected by drill hole temperatures up to 300 degrees Fahrenheit.
4. It is built using either a Geiger-Muller Counter or a Scintillation detector.
5. It operates at a recording speed which minimizes rig time.
6. It is ruggedly constructed and gives a minimum of trouble in the field.
7. It can be run either separately or simultaneously with the Neutron instrument.
8. The resulting log is calibrated in an easily used unit: Micrograms of radium-equivalent/ton of formation.
9. Errors due to hole conditions which affect the log can be eliminated in quantitative interpretation by the use of departure curves.
10. The service is available in all Schlumberger locations.
11. The logs are recorded on film and are immediately available to the oil operator in the field.

The Schlumberger

neutron log



Safety is primary on the Schlumberger Neutron Operations

Neutron sources are very radioactive — and hence very dangerous. Schlumberger has designed protective equipment which absolutely prevents harmful exposure to either drilling crews or Schlumberger personnel. The connection of the highly radioactive source to the neutron sonde is made within the thick lead protective carrier. Then, the entire assembly passes through the carrier into the hole, thus eliminating any direct exposure to the source.

Neutrons are electrically neutral particles with a mass approximating that of hydrogen atoms. In the Neutron logging operation, these particles are emitted at high velocity from a special source. They move randomly into the formation around the source and collide elastically with atoms of different substances. Due to the equivalence in masses, the collision of neutrons with hydrogen atoms causes a loss in their velocity and their eventual capture by atoms of chlorine, sodium, hydrogen, silicon, etc. Each capture is accompanied by the emission of powerful gamma rays called "gamma rays of capture." These gamma rays are in turn detected by a counter in the logging instrument which is placed a certain distance from the source.

When the hydrogen atom concentration is large, the neutrons are slowed and captured close to the source, and the resulting gamma rays do not reach the counter. On the other hand, when the hydrogen atom concentration is small, the neutron travel is greater and many of the gamma rays of capture are detected by the counter. Thus, the response of the counter varies inversely with the hydrogen atom concentration of the formation.

In addition to the gamma rays of capture, two other types of gamma ray activity exist near the counter:

1. Natural formation gamma rays — the type recorded in the normal gamma ray logging operation.
2. Gamma rays emitted from the source along with neutrons.

Since only the gamma rays of capture are of interest in neutron logging, it is essential that the other gamma rays be eliminated, or at least minimized, at the neutron detector. Fortunately, the unwanted gamma rays have a lower energy level than the gamma rays of capture. Because of this, it is possible to effectively shield, and so construct the counter that it detects only the desired rays. Moreover, the neutron source is made so powerful that the radiation of capture completely predominates the other activity.

WHAT THE NEUTRON LOG MEASURES

From the foregoing discussion, it is demonstrated that the variations on the Neutron log are due largely to changes in the hydrogen concentration in the formation. Furthermore, a fundamental relation exists between the hydrogen concentration and the liquid filled porosity. It follows, then, that any formation conditions which alter the porosity, the hydrogen content, or both, will affect the neutron response. Briefly then, the Neutron log variations are due to:

1. Changes in lithology.
2. Changes in porosity in a liquid filled medium.
3. Changes in hydrogen concentration by virtue of a change in the type of interstitial fluid — oil, gas, or water. Normally, oil and water respond about the same on the Neutron log, but often gas will be detected because of a decreased hydrogen content.
4. Variables such as hole size, nature of mud, casing, etc.

In these special test pits, hole conditions generally encountered in oil wells can be duplicated. Correction charts, prepared from radioactivity measurements under varied conditions, are used to obtain true formation radioactivity for quantitative interpretations.

uses of the Neutron Log

It has already been explained that the Neutron log can be used under the same well bore conditions as the Gamma Ray log. Briefly, its important applications are:

A substitute for the resistivity log: the Neutron log, like the Gamma Ray log, can be run in cased holes as well as open holes. Furthermore, the type of mud has little effect on the character of the curve. As already mentioned, the Gamma Ray log is very useful as a substitute curve for the S. P. when hole conditions prevent the use of, or adversely affect, the electrical log. Similarly, the Neutron log is an excellent substitute for the resistivity log when such conditions prevail.

An aid in perforating depth control: The Neutron log can be used as an aid in perforating depth control in the same way as the Gamma Ray log. It can be run in conjunction with a casing collar log and the well perforated by direct reference to open-hole logging depths.

As a means of recognizing gas-bearing formations in uniformly porous and shale-free formations: This is possible because gas has a lesser hydrogen concentration than either water or oil.

A means of determining porosity index: It has been recognized since the early days of Neutron logging that the response was a function of the hydrogen concentration and hence should be related to porosity. The recent improvements in instrumentation have enhanced considerably the reliability of such determinations, and in fact made them more or less routine.

SCHLUMBERGER METHODS OF POROSITY DETERMINATION

Method 1 — Calibration in the borehole, or formation calibration: This method is an empirical one based on the comparison of core analysis with Neutron values in many wells. Experience has shown that the relationship established between porosity and neutron deflection is valid in most hard rock areas where porosities are low. The method is illustrated in Figure 3 which includes a section of a log with the porosity calibration added. The graph is a straight line relation with porosity plotted on a logarithmic scale and neutron deflection plotted on a linear scale. In the example, the slope of the curve is established by the plotted points from core analysis.

Although such points from core analysis are helpful, the method has been found reliable without them. In such cases, it is necessary only to record the Neutron log through a section known to be very tight in the area (one or two percent porosity). This zone which will give a maximum deflection on the Neutron curve, will establish the lower end point of the graph. See point A on the chart. The upper end point (B) at the 100% porosity level, in the absence of known plotted porosity values, is placed at approximately 50 neutron counts on the horizontal scale. This value is dependent on several variables, including hole size, and must be reached empirically from experience in the area. It is substantiated by the fact that Gamma Rays of capture are still detected when the neutron insturment is immersed in a large vessel of fluid, i. e. 100% porosity. By drawing a straight line between the minimum point and maximum point, the calibration is accomplished and intermediate porosity values can be read directly from the neutron deflection. It is to be noted that some latitude in establishing the slope of the curve results in only a small difference in porosity reading over the range generally encountered in hard rock areas.

Method 2 — Universal calibration method:

All Schlumberger instruments are calibrated in counts per second on the surface by using a standard test source. It follows, then, that standard test conditions of known porosities, hole size, mud weight, casing or open hole, etc., can be set up on the surface and calibration charts developed for these conditions. Schlumberger is presently developing such charts. From experiments conducted to date, it appears that very excellent porosity checks will be possible. The only drawback to the method is the necessity for numerous charts to meet all combinations of the bore hole conditions.

Limitations of Porosity Measurements:

In using neutron deflections, or calibrations, as a measure of porosity, certain limitations must be recognized.

1. The neutron curve measures a total porosity including that of shale within the porous formation. It measures effective porosity only in those formations entirely free of shale. Fortunately, the examination of the gamma ray curve will generally give a fair estimate of the shale content in a formation.
2. In the absence of some core data the formation calibration method applies only when the section logged is sufficiently long to include at least one of the low porosity limestones in the region.
3. When using the formation calibration method hole conditions (open hole or cased hole and hole diameter) must be the same, in the low porosity interval as in the zone where porosity determinations are being made. In the universal calibration method, these conditions must also be known to select the proper correction charts.

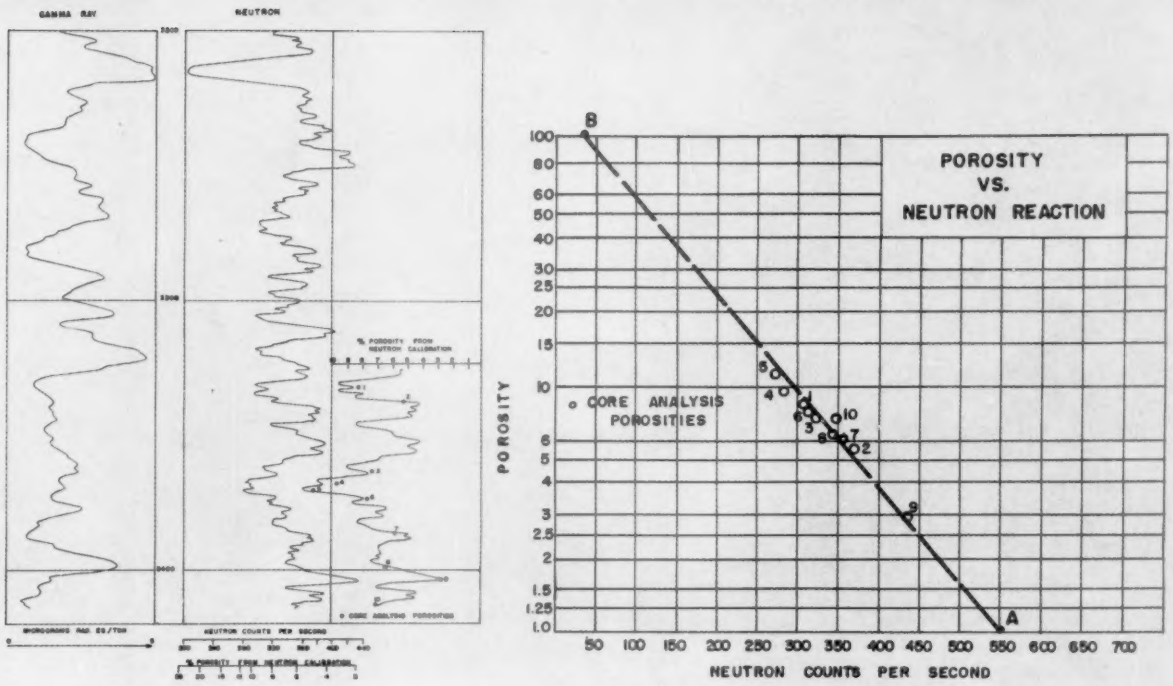


FIG. 3. Gamma Ray-Neutron Log calibrated to give direct porosity readings. The continuous record of porosity was derived from the Neutron curve. The calibrating chart of Porosity vs. Neutron Reaction, shown at right, was established from the limited core data plotted.

advantages of the Schlumberger Neutron Instrument

1. It operates satisfactorily in cased and open holes, and in all kinds of drilling mud.
2. It operates satisfactorily in drill hole temperatures up to 300° Fahrenheit.
3. The log is recorded on film and delivered to the client without retracing.
4. It can be run at recording speeds which minimize rig time.
5. It registers excellent formation detail because of (a) powerful neutron source (b) a highly efficient pulse counter and (c) effective shielding of the source from the counter.
6. It can be run separately or combined with the Gamma Ray instrument.
7. Its response is calibrated in number of counts per second, which can be translated into porosity values by use of proper charts.
8. The neutron log can be used directly as a measure of porosity, if a low porosity zone is contained in the recorded section.
9. It is built to the usual high Schlumberger standards and gives a minimum of trouble at the well.
10. It is available in all Schlumberger locations.
11. Extreme care has been taken in design of the instrument to eliminate radiation hazards.

a guide for the use of Radioactivity Logs

From the above discussion, it is apparent that Neutron and Gamma Ray logs can be used under very wide and diverse conditions. For the best log interpretation, it is necessary to run the logs in conjunction with various other logging methods. The following is suggested as a guide:

1. In cased holes — Neutron Log plus Gamma Ray log.
2. In empty holes, or oil-base muds — Neutron Log plus Gamma Ray Log; plus Induction Log.
3. In Salty Muds — Gamma Ray Log, Laterolog, or Microlaterolog supplemented by the Neutron Log.
4. In normal water-base muds — Electrical Log, Microlog, supplemented by Neutron Log and possibly Microlaterolog. A direct comparison of the MicroLog and Neutron under these conditions will detect a gas zone.
5. For perforating depth control — The Gamma Ray Log; or possibly Neutron Log, if good correlation does not exist between Gamma Ray and S. P.

First in the field...Foremost in research

SCHLUMBERGER WELL SURVEYING CORPORATION

Printed in U.S.A.

IF YOU PRODUCE, TRANSPORT or REFINE OIL....

Tretolite Company products and services are designed to help you overcome troublesome problems such as

EMULSIFICATION	Tret·O·lite **DEMULSIFIERS**	Efficient, assuring a fast break, low cuts; rigidly controlled manufacture to insure uniformity; proved more economical in oil fields everywhere.
WASTE OIL DISPOSAL	Tret·O·lite **WATER DE-OILERS**	Remove hydrocarbon stream pollutants with high degree of efficiency; in addition to prevention of nuisance, valuable oil often is salvaged.
CORROSION	KONTOL **CORROSION INHIBITORS**	Prevent corrosion in pumping equipment, pipe lines, tankers and refineries. A preventive measure recognized as one of the most effective available.
SCALING	S.P. **SCALE PREVENTIVES**	Effective both in field and refinery. Prevent adherence of scale-forming inorganic solids on metal surfaces of production and refining equipment.
SALT FOULING	Tret·O·lite **DESALTING**	Efficiently removes salts, solids and other impurities which damage and plug refining equipment, cause frequent shut-downs, high maintenance costs and retarded throughput.
PARAFFIN ACCUMULATION	SOLVO **PARAFFIN REMOVERS**	Often useful in preventing accumulation of line-plugging paraffins and asphaltines. Have both solvent and detergent qualities.

For complete information on any or all of these Tretolite Company services, call your Tretolite man.

TRETOLITE COMPANY

A DIVISION OF PETROLITE CORPORATION

369 Marshall Avenue, Saint Louis 19, Missouri

5515 Telegraph Road, Los Angeles 22, California

TKFR 54-3

DO YOU KNOW HOW MUCH CORROSION COSTS PRODUCERS EACH YEAR?

In a survey conducted by the National Association of Corrosion Engineers, covering 537 "sweet" oil wells and 3,052 "sour" oil wells, 30% of the "sweet" wells and 80% of the "sour" showed evidence of corrosion attack. A survey conducted by the Natural Gasoline Association of America showed that out of 2,466 scattered gas and gas condensate wells surveyed, 46% showed corrosion damage and metal losses. It has been estimated that the overall cost of corrosion on producing oil properties in the United States runs as high as $500.00 per well . . . a total of approximately $250,000,000.00 annually. Corrosion cost in gas and gas-condensate wells has been estimated at approximately $4.30 per MMCF of gas produced, or an annual total of $13,000,000.00. The total cost of corrosion in all these wells is $263,000,000.00!

While such figures certainly reflect the tremendous cost of corrosion to producers in general, they may not show what the losses due to corrosion are on your properties. Why not ask your Kontol engineer for a corrosion survey? There is no obligation, and he can show you how Kontol inhibitors help you stop these profit-cutting corrosion losses.

For complete information call your Tretolite man.

TRETOLITE COMPANY

A Division of Petrolite Corporation

369 Marshall Avenue, Saint Louis 19, Missouri
5515 Telegraph Rd., Los Angeles 22, California

CORROSION PREVENTIVES

Prevent corrosion of carbon steel and alloys

Stop hydrogen embrittlement and blistering

Are easy to apply. Can be pumped, dumped, lubricated

Available also in solid stick form

Safe, easy to handle. No extraordinary precautions required

Do not complicate scaling or emulsification problems

Do not deposit formation-plugging precipitates

Chemicals and Services for the Petroleum Industry

DEMULSIFYING · DESALTING · WATER DE-OILING
CORROSION PREVENTING · SCALE PREVENTING
PARAFFIN REMOVING

IT WILL PAY YOU TO HAVE ALL THE FACTS ON

KONTOL

KFB 54-10

SAVE RIG TIME!

... WITH Eastman DROP-TYPE MULTIPLE SHOT SURVEYING SERVICE

Eastman's new drop-type multiple shot surveying service is the fastest, most accurate magnetic directional surveying method known.

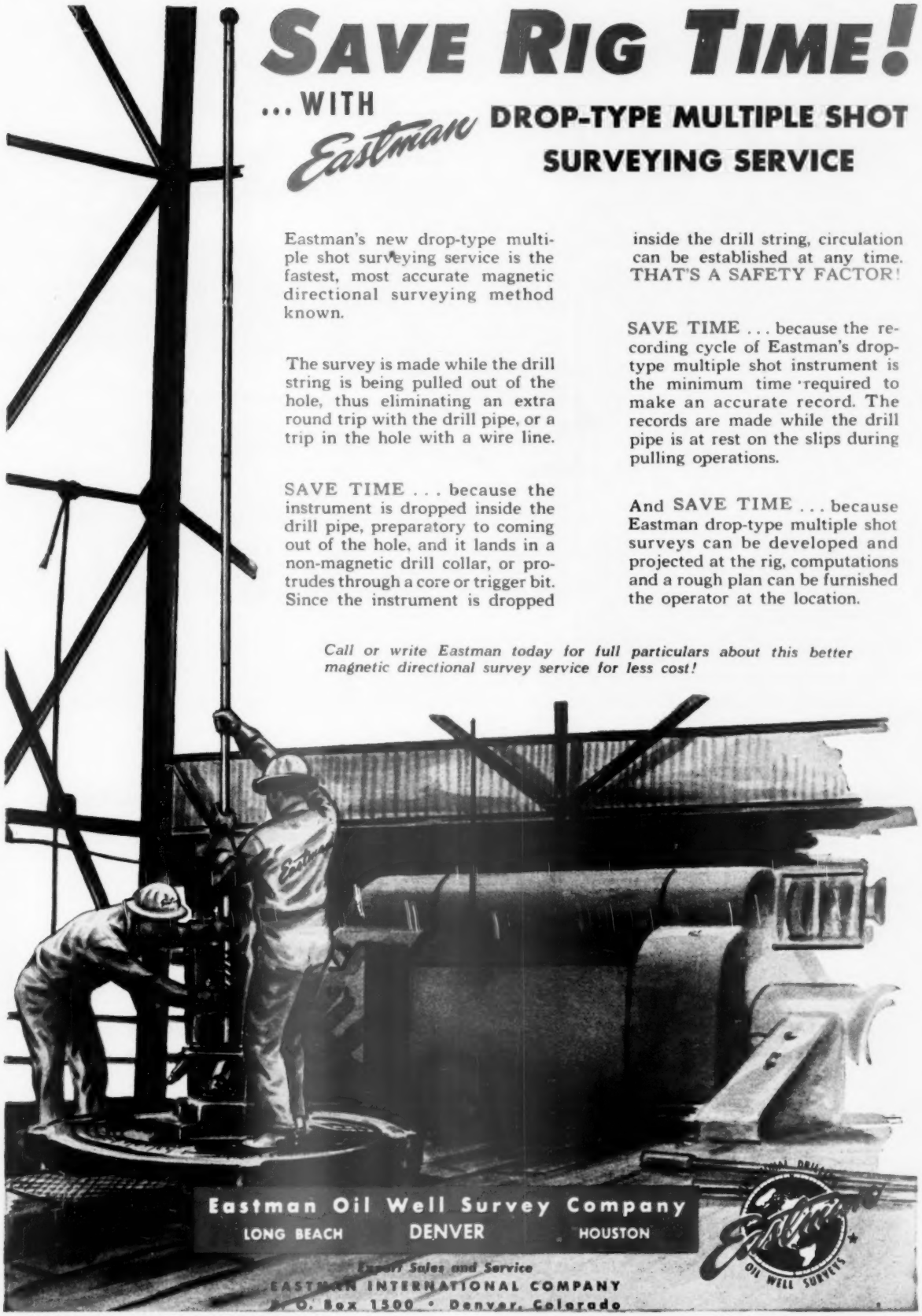
The survey is made while the drill string is being pulled out of the hole, thus eliminating an extra round trip with the drill pipe, or a trip in the hole with a wire line.

SAVE TIME . . . because the instrument is dropped inside the drill pipe, preparatory to coming out of the hole, and it lands in a non-magnetic drill collar, or protrudes through a core or trigger bit. Since the instrument is dropped inside the drill string, circulation can be established at any time. THAT'S A SAFETY FACTOR!

SAVE TIME . . . because the recording cycle of Eastman's drop-type multiple shot instrument is the minimum time required to make an accurate record. The records are made while the drill pipe is at rest on the slips during pulling operations.

And SAVE TIME . . . because Eastman drop-type multiple shot surveys can be developed and projected at the rig, computations and a rough plan can be furnished the operator at the location.

Call or write Eastman today for full particulars about this better magnetic directional survey service for less cost!



Eastman Oil Well Survey Company

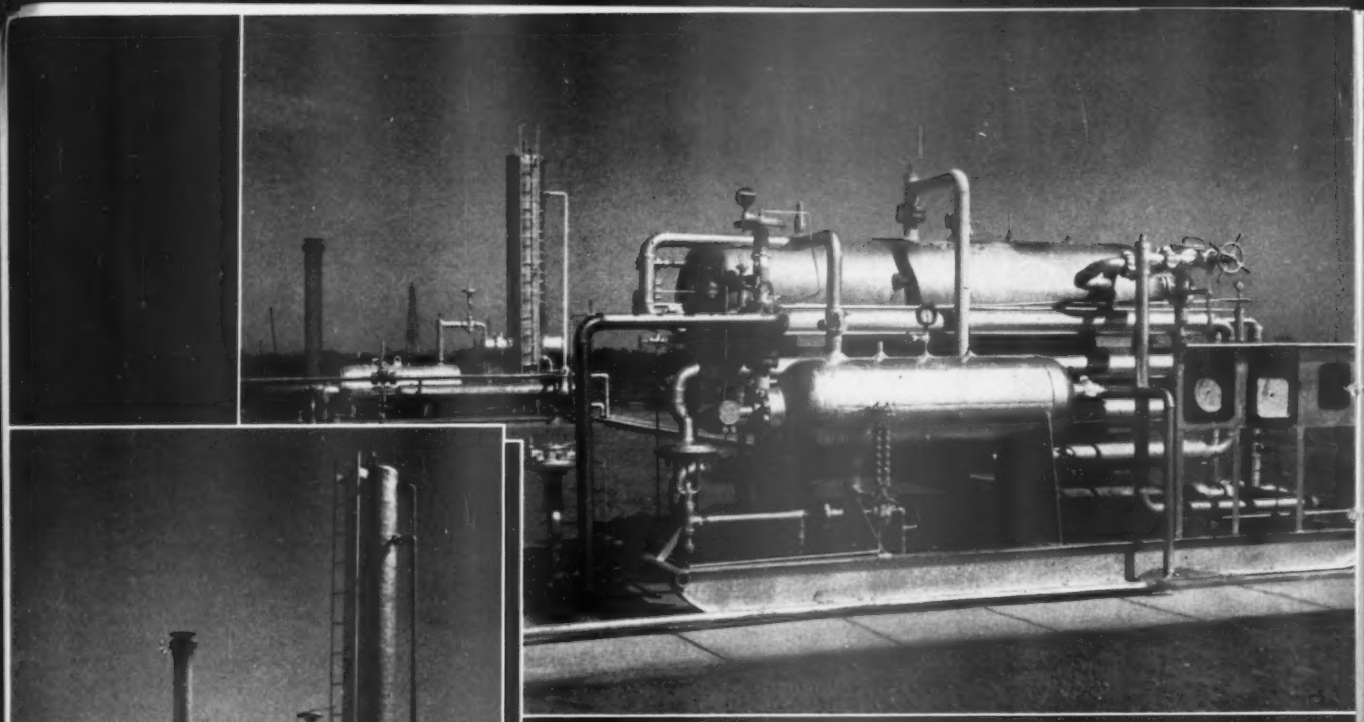
LONG BEACH DENVER HOUSTON

Export Sales and Service

EASTMAN INTERNATIONAL COMPANY

P. O. Box 1500 • Denver, Colorado

Eastman OIL WELL SURVEYS



A 15 MMCFD, 1000# W.P. LTX UNIT and 500 BBL./DAY, 125# W.P. STABILIZING DESORBER

A NATIONAL "LTX® SYSTEM"

PER UNIT VOLUME OF WELL EFFLUENT PRODUCED

GIVES

1. Maximum Stable Distillate Recovery
2. Maximum High Pressure Gas Sales
3. Maximum Trouble Free Performance

PLUS

The ability to operate with or without the injection of Glycol or other hydrate inhibitors.

It's a National®

NATIONAL TANK COMPANY

TULSA, OKLAHOMA

7-11-53

AIME

PETROLEUM TRANSACTIONS

COMPARISON of METHODS for ANALYZING a WATER DRIVE FIELD, TORCHLIGHT TENSLEEP RESERVOIR, WYOMING

F. M. STEWART
MEMBER AIME
F. H. CALLAWAY
R. E. GLADFELTER
JUNIOR MEMBERS AIME

STANOLIND OIL AND GAS CO.
TULSA, OKLA.

T. P. 3889

ABSTRACT

In this paper oil initially in place is calculated by the various methods commonly used for analysis of water drive fields using data available as time progresses. Rate and pressure are predicted by means of the same methods using data available at the end of two years' history. These predictions are then compared with subsequent performance permitting an evaluation of the methods, which are Modified Schilthuis, Simplified Hurst, van Everdingen et al (1952), and the Electric Analyzer.

INTRODUCTION

Several variations of the material balance equation, differing in the term used to evaluate water influx, are in common use for estimating oil in place, predicting rate and volume of water influx, and forecasting producing rates and reservoir pressure in water drive reservoirs. The electric analyzer with an electrical network set up to simulate the oil reservoir and aquifer and their contained fluids may be used for the same purpose.

Examples of the application of one or another of these methods have appeared in the literature. The accuracy and reliability of the material balance for calculating oil in place have been covered.[1] However, there have been few articles in which more than one method has been applied to an actual field allowing a comparison. It is felt that a field example, simple in nature, where the Modified Schilthuis, Simplified Hurst, van Everdingen et al (1952), and the Electric Analyzer have been applied would be of benefit in providing an evaluation of these methods as to their comparative usefulness and reliability in calculating initial oil in place and predicting performance.

The Torchlight Tensleep reservoir is a small field in a large aquifer. The reservoir oil is greatly undersaturated, having a bubble point of only 55 psi and 2 cu ft/bbl of gas in solution. Changes in the reservoir volume factor in the range of pressures encountered are small, meaning little error in converting production to reservoir conditions. The pressure has declined from 1,618 psi initially to 137 psi during the first four and one-half years. Water production has been negligible. For Torchlight, the material balance equation as discussed later is considerably simplified by the omission of terms having to do with free gas. Thus with simpler equations, less variables to consider, the large pressure drop, the absence of a gas phase, and rapid pressure-rate adjustments, which mean an unusual amount of history in a short time, the reservoir appears suitable for comparing the methods listed above.

GENERAL INFORMATION ON THE FIELD

The Torchlight field is located on the eastern side of the Big Horn Basin, Big Horn County, Wyo., approximately 3 miles east of the town of Basin. The Tensleep reservoir was discovered in September, 1947. It lies at a depth of about 3,000 ft and produces oil of 35° API gravity. A total of five wells have been completed in the Tensleep, but only four are now producing. The reservoir is well defined in areal extent in that a total of 13 wells have penetrated the Ten-

[1]References given at end of paper.

Manuscript received in Petroleum Branch offices Sept. 24, 1953. Paper presented at Petroleum Branch Fall Meeting in Dallas, Oct. 19-21, 1953.

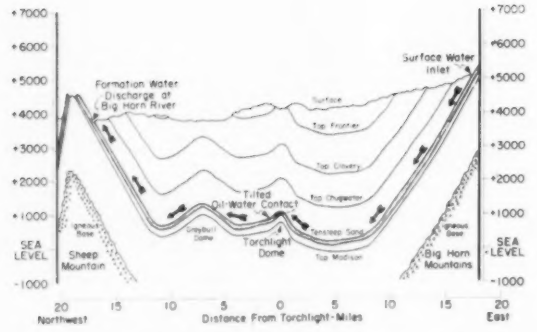


FIG. 1 — GENERALIZED CROSS-SECTION, SHEEP MOUNTAIN-TORCHLIGHT-BIG HORN MOUNTAINS.

sleep. Several of these wells lie outside the productive limits of the Tensleep reservoir.

The water drive recovery mechanism is usually associated with formations of wide areal extent having continuous permeability over a large area in the vicinity of the reservoir. The Tensleep is a "blanket" sand fitting this description.

The Tensleep outcrops in the Big Horn Mountains approximately 15 miles east of the field at elevations of roughly 5,000 to 6,500 ft above sea level, although a few creeks cross it at slightly lower elevations. It also is exposed where the Big Horn River cuts through Sheep Mountain some 17 miles northwest of the field. The elevation of the Tensleep where it is cut by the river is about 3,740 ft.

With intake of surface water into the formation outcrop at high elevations along the west edge of the Big Horn Mountains and discharge from the exposure along the river at much lower elevations, movement of water through the formation occurs. This is accompanied by a dynamic pressure gradient toward the point of water discharge. These conditions are illustrated in the regional cross-section, Fig. 1.

The original pressure of 1,618 psi at plus 1,000-ft datum at Torchlight is about 200 psi above that which would be expected from the surface elevation of 4,075 ft at the field and a fresh water gradient of .433 psi/ft of depth. The water table at Torchlight is tilted 140 ft from southeast to northwest through a distance across the productive area of about ⅞ of a mile. This tilt is equivalent to a differential of about 20 ft of water head or 9 psi over the same distance. This conversion may be made by use of Hubbert's[2] equation

$$\frac{\partial h}{\partial x} = \frac{\partial z}{\partial x}\,\frac{\rho_w - \rho_o}{\rho_w}$$

In this equation, $\frac{\partial h}{\partial x}$ is the rate of increase of total head of water along the interface in the x direction, $\frac{\partial z}{\partial x}$ is the tilt or slope of the oil-water interface in the same direction, and ρ_w and ρ_o are the densities of the water and oil, respectively, at reservoir conditions.

The map, Fig. 2, shows the anticlinal structure of the field, the shape of the oil reservoir, and the intersection of the oil-water contact with the top and base of the pay. No faults are evident in the vicinity of the field. The characteristics of the reservoir rock and fluids are tabulated below.

Productive Area	220 acres
Net Thickness of Pay	31 ft
Porosity	17 per cent
Connate Water Saturation	10 per cent
Permeability from Cores	204 mds
Permeability from PI's	87 mds
Initial Pressure	1,618 psi
Reservoir Temperature	100°F
Bubble Point	55 psi
Gas in Solution	2 cu ft/bbl
Reservoir Volume Factor at Bubble Point	1.0225
Viscosity of Oil	3.5 cps
Viscosity of Water	.60 cps
Compressibility of Reservoir Oil	7.7×10^{-6} vol/vol/psi
Compressibility of Reservoir Water	3.1×10^{-6} vol/vol/psi
Compressibility of Reservoir Rock	6.6×10^{-7} pore vol/bulk vol/psi

Of particular significance are the unusually low bubble point, solution ratio, and volume factor.

Production and pressure history of the field are shown by the lighter lines in the lower part of Fig. 3. In general, oil production increased rapidly to a peak within a few months after discovery followed by a period of rapidly decreasing rate as reservoir pressure and well capacity declined. Production rate was then reduced below capacity during 1949 and reservoir pressure responded by increasing rapidly. Production was increased in February, 1950, and since mid-1950 has been at well capacity. Withdrawals during this latter period are directly related to and controlled by the rate of water influx.

EVALUATION OF METHODS

The most common methods used to calculate oil in place and to analyze the performance of a water drive field have been applied to the Torchlight Tensleep reservoir.

By pore-volume, using the data in the table, initial oil in place was calculated to be 6.1 million bbls. Core data were available on seven wells, six of them located within the productive limits. In view of the number of wells drilled to the Tensleep defining the productive area and the extensive core coverage, the pore-volume estimate is believed to be fairly accurate, probably with less than 10 per cent error.

In all other methods of evaluating oil in place, the material balance equation is used. Assuming that all physical properties of the reservoir fluids are known, that pressure and production statistics of reasonable accuracy are available, and that a reasonable evaluation of the gas-cap volume ratio (if a gas cap exists) could be made, the only two unknowns in the equation are N, the original stock tank oil in place, and W, the cumulative water encroachment.

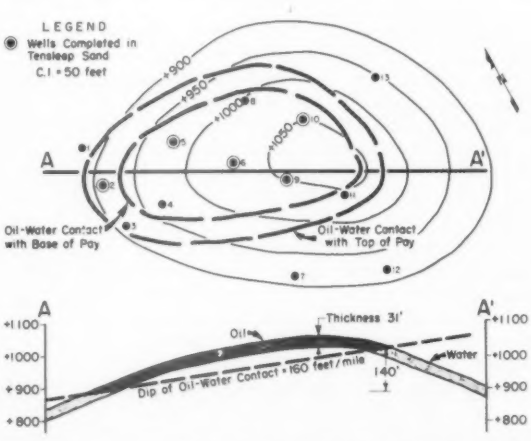


FIG. 2 — STRUCTURE AND CROSS-SECTION, TORCHLIGHT TENSLEEP RESERVOIR.

The methods differ only in the manner in which W is evaluated, and all require the simultaneous solution for the most likely values of the two unknowns, usually arrived at by the method of least squares.

The material balance equation may be written as follows, using nomenclature listed in a later section:

$$n\beta + [n\ (r_a - S) - N(S_o - S)]\ a + w - N(\beta - \beta_o) - m\ N\ \beta_o \left(\frac{a}{a_o} - 1\right) = W \quad . \quad (1)$$

At Torchlight, in spite of the large pressure drop which has occurred, pressure has never declined to the bubble point of 55 psi. Since no free gas has existed, $r_a = S$; $S_o = S$; and $m = 0$. The material balance may be simplified and rearranged to

$$N\ (\beta - \beta_o) = n\beta + w - W \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

As long as the pressure remains above the bubble point the difference in reservoir volume factors $(\beta - \beta_o)$ may be replaced by $C\beta_o(P_o - P)$. Thus the equation as applicable to Torchlight is

$$N\beta_o C\ (P_o - P) = n\beta + w - W \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Regardless of how W is determined, solution for N is inversely proportional to the compressibility factor used. Where undersaturated crudes are involved, serious error in the calculation of N can result by neglecting rock compressibility.[3] In this case, $C = 7.7 \times 10^{-6}$. However, effective compressibility, C_e, including connate water and rock compressibilities, is equal to $C + (C_w \times$ vol connate water/vol oil$) + ($Cr $\times$ vol rock/vol oil$) = 12.4 \times 10^{-6}$ vol/vol of oil/psi. Calculated N using the compressibility factor for oil but neglecting connate water and rock compressibilities would be 12.4/7.7 or 1.61 times greater than the actual N, assuming all other data including W are accurately known.

Examination of the equation also shows that at pressures near original a small error in pressure measurements could make a very great error in the N determined. As $(P_o - P)$ becomes greater, errors in pressure measurements become less significant.

Methods of analysis applied to Torchlight are as follows:

Modified Schilthuis
Simplified Hurst
van Everdingen, et al (1952)
Electric Analyzer

With the first three, oil initially in place was calculated from cumulative data available at successive times. Using data available at the end of two years' history (November, 1949) and average calculated oil in place as of that date, future rate and pressure performance were predicted by each method. The predictions were then compared with subsequent performance, permitting an evaluation of the methods. Similar predictions and comparison were made using the electric analyzer and pore-volume oil in place.

For the predictions in each case, the production rate was maintained at 500 B/D as long as wells had the capacity to produce that amount, and capacity thereafter. The capacity of the wells was evaluated using a composite PI of 3.2 from field data and minimum producing bottom hole pressure of 15 psi. These conditions conform closely with the actual. Water production was assumed to remain at roughly 2 per cent, which also agrees closely with the actual.

MODIFIED SCHILTHUIS METHOD[4,5]

In this method water influx is related to pressure and time by means of a constant as follows:

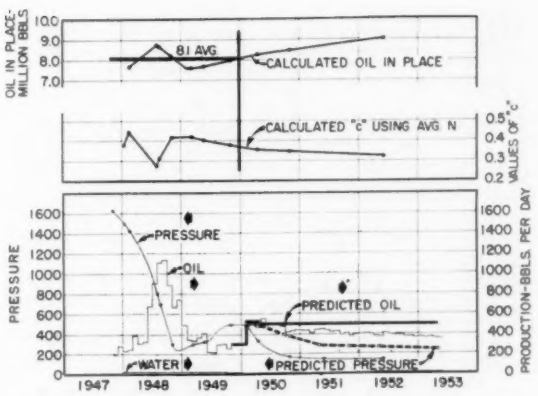


FIG. 3 — MODIFIED SCHILTHUIS METHOD, CALCULATED N AT SUCCESSIVE TIMES AND PREDICTIONS FROM NOVEMBER, 1949, COMPARED WITH ACTUAL PERFORMANCE.

$$N\beta_o C_e(P_o - P) = n\beta + w - c\ \Sigma_o^{\Theta}\ \Delta P \Delta\Theta \quad . \quad . \quad (4)$$

Assumptions are that steady state conditions exist and that rate of water influx into the reservoir at any time is proportional to the difference between the initial pressure (P_o) and the field pressure (P), and to the area exposed to water encroachment on the field's boundary. The proportionality constant, c, includes the formation permeability, water viscosity, and area of encroachment on the field's boundary.

Fig. 3 shows the calculated oil in place, N, from the Modified Schilthuis method using reservoir data cumulative to the time of the points plotted. When water is replacing a high percentage of withdrawals after the initial large pressure drop, N is continually increasing. Using the average N of 8.1 million bbls determined from the first two years' history, the proportionality constant, c, has been calculated and is found to be steadily decreasing. Obviously, predictions of reservoir pressure and influx rate based on this method and using a constant c will be in error.

Predictions of rate and pressure made using data available as of November, 1949, N of 8.1 million bbls, and c of .38, appear on Fig. 3. Compared to subsequent history, also shown on Fig. 3, a large degree of error is evident.

If pore-volume N of 6.1 million bbls had been used, values of calculated c would decrease from 1.12 to .423 from the first point to November, 1949, and predictions would have been just as much or more in error.

The direction of the error in predictions is as expected because this method does not take into account the gradually lengthening travel path of the encroaching water. Although it is simple and easily applied, its application is limited because of neglecting transient conditions. Transient conditions cause a lower water pressure gradient, a gradually decreasing encroachment rate, and consequently lower reservoir pressure with time than would be expected under the steady state assumption.

SIMPLIFIED HURST METHOD[6]

This method is similar to the previous one but introduces logarithm of time into the denominator of the W expression to approximate the actual variation in $(P_o - P)$ with time when the field is producing at constant rate.

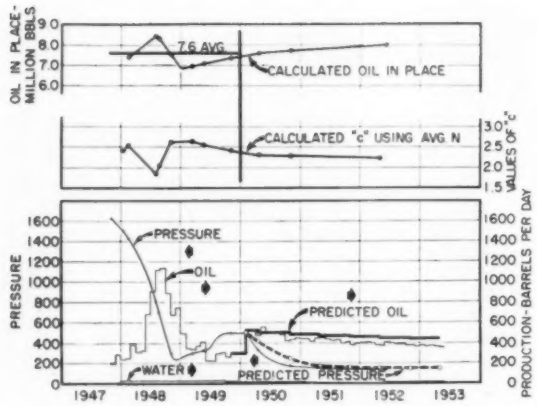


FIG. 4 — SIMPLIFIED HURST METHOD, CALCULATED N AT SUCCESSIVE TIMES AND PREDICTIONS FROM NOVEMBER, 1949, COMPARED WITH ACTUAL PERFORMANCE.

$$N\beta_o C_e (P_o - P) = n\beta + w - c\Sigma_o^{\Theta} \Delta P \Delta\theta / \log \theta \quad . \quad (5)$$

The proportionality constant, c, is a different number than the one in the previous equation.

Oil in place was again calculated using cumulative data at various times and appears on Fig. 4. As in the previous case the calculated N is increasing after the initial large pressure drop; however, values of N are consistently closer to the pore-volume determination of 6.1 million bbls. Conversely, c, determined using an average N of 7.6 million bbls calculated for the first two years, is decreasing. However, values for both are more consistent than those calculated using the Modified Schilthuis method.

Predictions of rate and pressure using N of 7.6 million bbls, c of 2.38, and other data as of November, 1949, appear on Fig. 4. The predicted pressure falls off more rapidly than by the previous method and the capacity of wells declines below 500 B/D as the pressure decreases. These predictions are closer to the actual rate and pressure behavior subsequently observed than similar predictions for the preceding method, but considerable error is still apparent. This is expected from comparison of the trends of the calculated c's using single values for N as shown on Figs. 3 and 4.

If pore-volume N of 6.1 million bbls had been used, calculated c would have decreased from 4.71 to 2.60 for successive times up to November, 1949, and no improvement in the accuracy of predictions would have resulted. Little more engineering time is involved in application of this method than in the preceding one.

VAN EVERDINGEN, ET AL (1952) METHOD[6]

A new method for calculating oil in place was introduced in 1952 by van Everdingen, Timmerman and McMahon. It combines the material balance equation with the water influx equation of van Everdingen and Hurst (1949).[3] For Torchlight, the combined equation resolves to

$$N\beta_o C_e (P_o - P) = n\beta + w - B\Sigma \Delta p Q_T \quad . \quad (6)$$

B is a proportionality factor to convert reduced units into barrels and is different from the factors in the previous methods; Δp is the successive pressure drop occurring during successive time intervals of equal duration, psi; and Q_T is a dimensionless function of production time in reduced units T and the ratio of aquifer radius to oil reservoir radius. Values of Q_T as a function of T for an infinite aquifer are given in Table 1 of Reference 8. The procedure for obtaining the summation of $\Delta p Q_T$ for various times is covered in Reference 6.

As in the other methods there are only two unknowns in the above equation, namely N and the proportionality factor (B in this case). These may be determined by the least squares method if two or more of the equations can be written, i.e., if data are available for at least two time intervals. However, in order to find the correct values of $\Delta p Q_T$ it is necessary to determine T, which may be approximated from the equation

$$T = \frac{kt}{f\mu C_e r_b^2} \quad . \quad (7)$$

For Torchlight, using the values for porosity, permeability, viscosity of water, and combined compressibility of water and rock derived from the data in the table, $T = 477$ for the 1,643 days (four and one-half years) the field produced to May, 1952, and $\Delta T = 53$, for half-year intervals.

N and B have been calculated by the least squares method using cumulative data at the end of successive half-year intervals. If the correct time conversion were used, basic assumptions hold, and other data were reliable, values of N and B would not change. Fig. 5 shows values of N calculated for $\Delta T = 5$, 10, 40, and 60. Obviously, the correct value for ΔT must lie between 5 and 10 and possibly very close to 5, at which successive values of N are more consistent.

N corresponding to $\Delta T = 5$ is 6.1 million bbls which is in agreement with that calculated by pore volume. However, if time had been taken to determine N for values of $\Delta T = 6$ or 7, slightly larger values of N would have resulted as can be seen by interpolation between the curves.

Using N of 6.1 million, B of 23.26, and values of Q_T for $\Delta T = 5$, rates were predicted from November, 1949, as shown on Fig. 5. A close check with actual performance is noted. Pressure values similarly would be fairly close to the actual, however, they are not plotted. The above values of N and ΔT were derived from information available through May, 1953. Referring to Fig. 5 again, it is highly unlikely that information available in November, 1949, would have been reliable enough to obtain a reasonable value for ΔT. Therefore, although a reasonably accurate forecast from November, 1949, was made using cumulative data through May, 1953, to fix the values of N and ΔT, a reasonable forecast would have been unlikely based only on data available to November, 1949.

OTHER MATHEMATICAL METHODS

There are two other mathematical methods of calculating water influx, other than those discussed above, which have appeared in the literature. These are called Hurst (1943)[7] and van Everdingen and Hurst (1949)[8] methods. In both, the water influx is determined independently of the material balance. Water influx is equal to a constant, which can be calculated from data normally available on the field, times a step function which is read from published charts or tables. In both, the constant is equivalent to the B in the van Everdingen, et al (1952) method. In the van Everdingen and Hurst (1949) method, T is calculated according to Equation 7. For Torchlight, the calculated ΔT for a half-year period is 53, compared to the more representative value of 5 which was found in the preceding

section to give the most consistent values for N. The proportionality constant was calculated to be 66.9 compared to B of 23.26. If the directly calculated values of 53 for ΔT and 66.9 for the proportionality constant had been used without any adjustment, the water influx determined obviously would be greatly in error.

The van Everdingen et al (1952) method, of course, was developed using the 1949 work as a basis and represents an improvement in that the correct T is approximated, and most probable N and B are determined from solution of simultaneous equations. Since the van Everdingen et al (1952) method is simply an improvement over the other two procedures, applications of the Hurst (1943) and van Everdingen and Hurst (1949) methods to Torchlight are not included.

In brief review of the mathematical methods already discussed, it is readily noted that the methods differ in allowance made for transients in the aquifer. The Modified Schilthuis method is simple but neglects these transients. The Simplified Hurst method requires little more engineering time, makes some allowance for the transient, and gives closer results. The van Everdingen et al (1952) method holds closely providing the basic data are reasonably accurate, the aquifer is fairly uniform in thickness, permeability, porosity, and its size is known, the character of the fluids in the aquifer does not change, and no other fields common to the aquifer have an appreciable effect on behavior of the field in question; however, much more engineering time is involved, especially in arriving at the correct value for T.

ELECTRIC ANALYZER[9,10]

The mathematical methods are somewhat laborious, which usually means the person making the analysis is limited to a single set of rock and fluid characteristics. With an electric analyzer, different combinations of these properties and other pertinent factors, such as size of aquifer and changes in the properties of the aquifer with distance, may be taken into account. Presumably all these factors could be adjusted until past performance were duplicated. This is an apparent advantage in the analysis of water drive performance with the analyzer compared to mathematical methods.

The pressure history of the Torchlight field up to

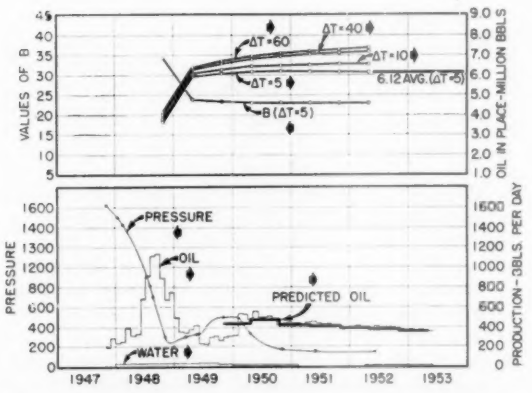


FIG. 5 — VAN EVERDINGEN ET AL (1952) METHOD, CALCULATED N AT SUCCESSIVE TIMES FOR VARIOUS VALUES OF ΔT AND PREDICTION FROM NOVEMBER, 1949, COMPARED WITH ACTUAL PERFORMANCE.

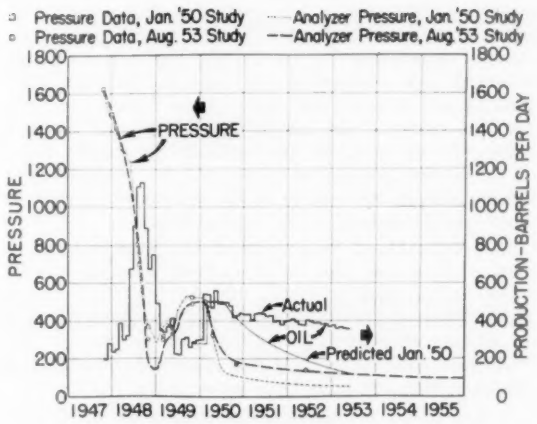


FIG. 6 — ELECTRIC ANALYZER STUDIES OF JANUARY, 1950, AND AUGUST, 1953, AND ACTUAL PERFORMANCE.

November, 1949, was matched on the electric analyzer by using 6.1 million bbls oil in place and by considering an aquifer acting only on the eastern edge of the reservoir. The latter assumption was made because water production and pressure gradients existing within the oil reservoir were interpreted at that time to mean that water encroachment was occurring principally on that side. At the time, it was found that the field performance could be reasonably duplicated with an aquifer extending 2.2 miles; however, the data could have been fitted equally well with an unlimited aquifer. At the time of this first analyzer study, geological data alone were not believed conclusive evidence that the aquifer was continuous past the 2.2-mile radius. Because the drop in pressure which had occurred was much more severe than at any other Tensleep reservoir in the Big Horn Basin, and since a large Tensleep field in the northern part of the Basin had practically no water influx at all, the use of the limited aquifer did not seem unreasonable.

Future pressure predictions were made with the 2.2-mile aquifer assuming a withdrawal rate of 500 B/D as long as the wells could make that amount, and capacity production thereafter. These predictions deviated appreciably from subsequent field performance as shown on Fig. 6. This, of course, was disturbing since a reasonable fit of past performance had been obtained.

A second analyzer study was conducted using data available through the first part of 1953 and using 6.1 million bbls oil in place. Several of the field pressure points used in the previous study were changed to eliminate the effect of water influx on pressure build-up during the shut-in period (these are shown by the circular points. The results of this study are shown on Fig. 6. The performance up to this time indicated that an aquifer of at least 5 miles radius was required to obtain an agreement between field performance and the analyzer representation. However, it was found that past performance could be duplicated with either an infinite aquifer or an aquifer of radius 5 miles. Therefore, at this time, from pressure performance history alone, it is not possible to further define the size of the aquifer, that is, determine how much greater than 5 miles its radius may be.

As seen from the behavior in Fig. 6 the size of the aquifer is one of the critical parameters governing future performance. The reliability of future predictions

depends on the size of aquifer assumed; however, the limits within which future pressure trends must fall can be determined. If an aquifer just large enough to match past performance is used the pressure predictions will give a lower limit of the future reservoir pressure curve. If an infinite aquifer is used in predicting future pressure performance, an upper limit of the reservoir pressure curve will be obtained. An infinite aquifer was used to obtain the analyzer pressure curve and prediction for the second study.

It is advisable to examine available geological information about the aquifer, its extent, continuity, etc. From recent geological data on the Big Horn Basin there is now good evidence, as described earlier, that an aquifer of essentially unlimited extent adjoins the Torchlight field. Therefore, the predictions using the infinite aquifer are considered more nearly correct.

It was found that the pressure history of the Torchlight field up to the first part of 1953 could be reasonably duplicated on the analyzer using oil in place values varying from 3.8 to 7.5 million bbls and varying slightly the aquifer properties. This means that reliable values of oil in place and aquifer size for Torchlight cannot be found simultaneously, which is in accordance with expectations since only a very small portion of the withdrawals is replaced by expansion of the oil.

CONCLUSIONS

The following conclusions are made on application of the various methods of analyzing a water drive field to the Torchlight Tensleep reservoir — a small oil reservoir in which pressure has been maintained above the bubble point by an effective water drive:

1. With the exception of pore-volume calculation of oil in place, no method gave either a reliable determination of oil in place or reliable prediction of producing rate and reservoir pressure using data available the first two years; however, using later data reasonable results for both oil in place and performance prediction were obtained by the van Everdingen et al (1952) method once reduced time, T, could be accurately determined.

2. In methods using the material balance, accuracy in determining oil in place and predicting producing rate and pressure is directly influenced by the allowance made in the water influx term for transient conditions in the aquifer. Consequently, in application to Torchlight, results by the Modified Schilthuis method were seriously in error; by the Simplified Hurst method, appreciably in error but somewhat better; by the van Everdingen et al (1952) method, fairly reasonable after reduced time, T, could be accurately determined.

3. The performance prediction made in 1950 with the Electric Analyzer was not reliable due to lack of definition as to the extent of the aquifer. The performance prediction prepared in August, 1953, is subject to the same basic limitation; however, the uncertainty of the prediction is much less as a result of the additional performance history.

ACKNOWLEDGMENTS

The authors wish to thank Robert Lewis and C. A. Bickel for their work in conducting the last electric analyzer study, L. E. Wilsey for his helpful suggestions on the analyzer work, and the management of Stanolind Oil and Gas Co. for permission to prepare and publish this paper.

NOMENCLATURE

N = Oil in place, stock tank bbls.
W = Cumulative water influx, bbls.
n = Oil produced, stock tank bbls.
w = Water produced, bbls.
β = Reservoir volume of 1 unit of stock tank oil and its dissolved gas at pressure P.
C = Compressibility of reservoir oil above its bubble point, vol/vol/psi.
C_w = Compressibility of water, vol/vol/psi.
C_r = Compressibility of reservoir rock, pore vol/bulk vol/psi.
C_e = Effective compressibility, vol/vol of oil/psi, for the reservoir computed from C, C_w, and C_r.
C_a = Combined compressibility of aquifer.
P = Reservoir pressure, psi.
r_s = Average gas oil ratio, cu ft/bbl, from P_o to P.
S = Gas in solution at pressure P, cu ft/bbl.
α = Reservoir volume of 1 unit of gas at standard conditions, when subjected to pressure P and reservoir temperature.
m = Fraction of reservoir volume originally occupied by gas.
Θ = Time from date of initial production, days.
f = Porosity, fraction.
μ = Viscosity of water, cp.
r_e^2 = Square of radius of oil reservoir, sq cm.
t = Time in days during which pressure drop has been operative.
k = Permeability in darcys.
T = Reduced time as defined by Equation 7.
$_o$ = Subscript denoting initial conditions.
Δ = Incremental change.

REFERENCES

1. Muskat, Morris: *Physical Principles of Oil Production*, McGraw-Hill, New York (1949), Chapter 9.
2. Hubbert, M. King: "Entrapment of Petroleum Under Hydrodynamic Conditions" *Bulletin* of AAPG (August, 1953), **37**, 1987.
3. Hall, H. N.: "Compressibility of Reservoir Rocks," *Trans.* AIME (1953), **198**, 309.
4. Schilthuis, R. J.: "Active Oil and Reservoir Energy," *Trans.* AIME (1936), **118**, 37.
5. Pirson, S. J.: *Elements of Reservoir Engineering*, McGraw-Hill, New York (1950), Chapter 7.
6. van Everdingen, A. F., Timmerman, E. H., and McMahon, J. J.: "Application of the Material Balance Equation to a Partial Water Drive Reservoir," *Trans.* AIME (1953), **198**, 51.
7. Hurst, W.: "Water Influx into a Reservoir and its Application to the Equation of Volumetric Balance," *Trans.* AIME (1943), **151**, 57.
8. van Everdingen, A. F., and Hurst, W.: "The Application of the Laplace Transformation to Flow Problems in Reservoirs," *Trans.* AIME (1949), **186**, 305.
9. Bruce, W. A.: "An Electrical Device for Analyzing Oil-reservoir Behavior," *Trans.* AIME (1943), **151**, 112.
10. Schaefer, Henry: "Extending the Application of Electric Analogy in Oil-reservoir Studies," *Trans.* AIME (1947), **170**, 62. ★★★

A MAGNETIC SUSCEPTIBILITY METHOD for the DETERMINATION of LIQUID SATURATION in POROUS MATERIALS

J. W. WHALEN | MAGNOLIA FIELD RESEARCH LABORATORIES
DALLAS, TEX.

T. P. 3893

ABSTRACT

The design, operation and evaluation of an instrumental method for the determination of fluid saturation in porous materials during multiphase flow studies is described. The presence of a magnetic tracer comprising approximately 20 per cent by weight of the aqueous phase is necessary in the utilization of this method.

The results of two-phase relative permeability studies on two samples of porous media are presented. The realizable accuracy of the magnetic susceptibility apparatus in fluid saturation determination is estimated to be 2 saturation per cent. The response characteristics of the instrument, together with its simplicity of operation and maintenance are sufficient to recommend its use in routine laboratory studies.

INTRODUCTION

The problem of fluid saturation determination in laboratory multiphase flow studies characterizing oil recovery processes is one which has been given exhaustive study. Briefly the requirements which are considered essential for a method serving this purpose are: (1) that the measurement be made external to the porous rock sample under study with no interruption of the fluid flow pattern, (2) the saturation indication must be independent of fluid distribution in the volume scanned by the measuring device, (3) the sensing element should have a small field of definition enabling several independent measurements to be made alone the length of a core sample, and (4) the properties of the fluid phases should not be too greatly influenced by required tracer substances.

Several methods of saturation determination have found acceptance as meeting most of the above requirements. These include resistivity,[1] X-Ray absorption,[2,3,4] radiotracers,[5,6,7] and neutron[8] diffraction. The merits of these techniques have been discussed elsewhere in detail and will not be considered here. It may, however, be pointed out that the elaborate instrumentation required by the methods mentioned above, with the exception of the resistivity method (which is undesirable from other standpoints) encourages the development of methods of saturation determination which, while meeting the requirements listed, are simple to operate and maintain.

It is the purpose of this paper to describe the instrumentation and evaluation of a technique for the determination of fluid saturation which combines relative simplicity with an accuracy and applicability comparable with methods now in practice.

DESCRIPTION OF THE METHOD

If the magnetic susceptibility of one of the fluid phases contained within a porous material is sufficiently greater than that of the remaining phases, the fluid content of the material with respect to that phase may be determined by an induction measurement. This may be accomplished by measuring the induced voltage in the secondary of a transformer which contains the porous sample and its interstitial fluids as a portion of the magnetic flux path. Since the fluids used in multiphase flow studies involving petroleum reservoir samples possess uniformly low magnetic susceptibilities, the use of a magnetic tracer in one of the fluid phases is required.

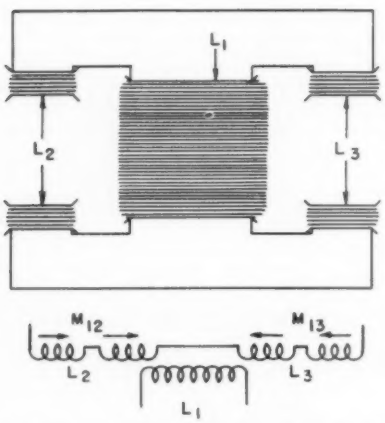
In view of the relatively high paramagnetic susceptibility of salts of the transition elements, together with their high water solubility, these compounds become logical choices as tracer materials. Cobaltous chloride, having a specific magnetic susceptibility of 17.5×10^{-6} cgs electromagnetic units, was used as the tracer material throughout this work, in a concentration of approximately 20 per cent by weight in the aqueous phase.

MAGNETIC SUSCEPTIBILITY APPARATUS

Basically, the magnetic susceptibility apparatus consists of a transformer serving as the detecting head, a

[1]References given at end of paper.

Manuscript received in the Petroleum Branch office Jan. 15, 1954. Paper presented at the AIME Annual Meeting in New York City, Feb. 13-17, 1954.



L_1 PRIMARY 780 TURNS NO.30 COPPER WIRE
L_2, L_3, EACH COIL 400 TURNS NO.35 COPPER WIRE

FIG. 1 — DETAIL OF TRANSFORMER HEAD FOR MAGNETIC SUSCEPTIBILITY MEASUREMENT OF CORE SATURATION.

nulling circuit for obtaining a zero signal prior to introducing the core sample and its interstitial fluids into the flux path of the transformer, a metering circuit for observation of the transformer response, and a stable power supply serving the transformer and nulling circuit.

The transformer used in this work was constructed with balanced secondary coils in an effort to eliminate the effects on the mutual inductance of temperature, stray electrostatic and electromagnetic fields, and humidity. Two air gaps were symmetrically located with respect to a central member around which the primary coil was wound. Secondary coils were wound about each arm of the air gap and the two secondaries were connected in series opposition. The transformer core was built up with 0.005-in. thick Conpernick* laminations insulated from one another by a baked-on coat of transformer dope except at a grounding point on each lamination. Details of the transformer construction are shown in Fig. 1.

The residual unbalance voltage from the two secondaries, resulting from an inability to wind the two sets of secondary coils so as to exactly cancel the opposing induced voltages, was matched with a voltage of equal amplitude and opposite phase from the nulling circuit. Amplitude control was accomplished by means of a helipot setting, and phase control was obtained from an inductive-capacitive network. A schematic circuit diagram is shown in Fig. 2.

A Southwestern Industrial Electronic Co. Model M oscillator having a frequency stability of 0.1 per cent and an amplitude stability of 1 per cent was used to supply power to the transformer and nulling circuit. The output voltage level at 1,000 cps was maintained at 20 volts throughout this work.

The amplification and metering circuit consisted of a Hewlett-Packard Model 450-A amplifier operating at 40 db gain, a 1,000-cps band-pass filter and a Hewlett-Packard Model 400-C vacuum tube voltmeter. The magnitude of the amplified readings was such that the 0.3-volt scale of the voltmeter was used for most signals. The voltmeter scale could be read with a precision of 1 per cent of full scale.

*Conpernick is the trade name of a high magnetic permeability alloy produced and distributed by Westinghouse Electric Co.

TABLE 1 — POROSITY OF SAND PACKS: COMPARISON OF POROSITY VALUES CALCULATED FROM GEOMETRY OF PACK WITH POROSITY VALUES MEASURED USING THE MAGNETIC TRACER.

Sand Mesh Size	Calculated Porosity %	Measured Porosity %
35-45	40.4	40.2
20-25	39.6	39.8

In order to ascertain that the sensitivity of the magnetic susceptibility apparatus remained constant throughout protracted studies, an iron-Lucite powder mixture was molded into a plug of the same dimension as the mounted core samples used in this work and readings were obtained on this standard during the multiphase flow experiments. The standard contained 75 micrograms of iron per 100 gms of Lucite powder.

INSTRUMENT CHARACTERISTICS

A series of tests was carried out to determine the utility of the magnetic susceptibility apparatus in liquid saturation determination. Various concentrations of cobaltous chloride solution were prepared by successive dilution of a 17 per cent (by weight) cobaltous chloride stock solution. These solutions, contained in a hollow Lucite cylinder, were placed in the transformer air gap and the voltmeter deflection noted for each solution. The response of the induced voltage in the transformer to the quantity of paramagnetic material present in the air gap is shown in Fig. 3. As a further check, the porosities of two sand packs were determined from the magnetic susceptibility reading. A comparison between the porosity value calculated from the sand density and geometry of the container and that found experimentally is shown in Table 1.

In considering what volume of a core sample placed in the transformer air gap is "scanned" by the measuring apparatus, the flux density in various portions of the magnetic field and the variation in flux density from point to point under various distributions of the tracer liquid is of interest. The flux density pattern was obtained using as a probe a small steel ball approximately 0.1 in. in diameter. The field strength was taken to be proportional to the voltmeter reading and isomagnetic lines were constructed in two planes as shown in Figs. 4 and 5.

The effect of tracer liquid distribution in the magnetic field of the measuring transformer on the induced voltage was determined as follows. A hollow Lucite cylinder was placed in the transformer air gap and tracer liquid added in increments. The voltmeter deflection was noted for each increment. In the first portion of this study added volume increments advanced the

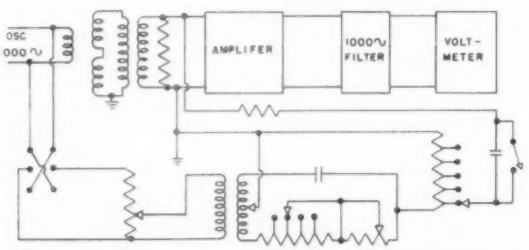


FIG. 2 — SCHEMATIC CIRCUIT DIAGRAM FOR MAGNETIC SUSCEPTIBILITY APPARATUS NULLING CIRCUIT.

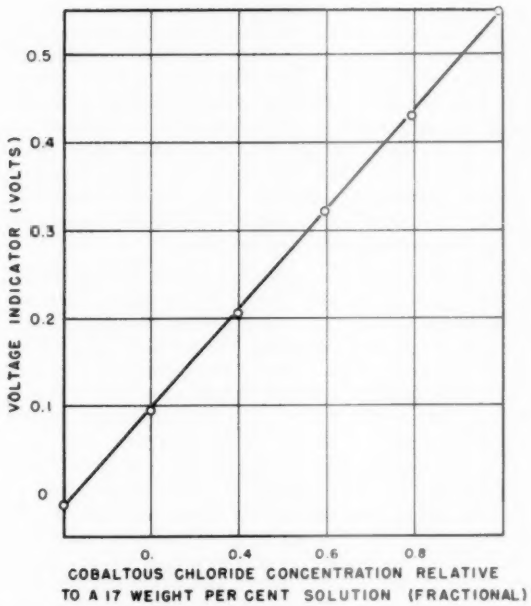


FIG. 3 — RESPONSE CHARACTERISTICS OF THE MAGNETIC SUSCEPTIBILITY APPARATUS.

air-liquid interface from a point beyond the influence of the magnetic field toward the air gap center of the transformer. Measurements were halted when the air-liquid interface reached the air gap center. In the second portion of the study, starting with no tracer liquid in the magnetic field, the air-liquid interface receded from the air gap center with each addition of liquid. Measurements were halted when further additions of liquid produced no change in the voltmeter indication.

These data are presented in Fig. 6 as a magnetic susceptibility profile of the fluid-filled hollow cylinder for two concentrations of tracer solution. Solutions containing 17 and 7 per cent (by weight) cobaltous chloride were used in this study, corresponding to a reduction in the saturation of a core sample from 100 per cent to 41 per cent with respect to the aqueous phase.

RELATIVE PERMEABILITY APPARATUS AND PROCEDURE

Dynamic two liquid-phase flow studies were carried out using two positive displacement pumps to deliver the required flow rates. Standard 250 ml volumetric pump barrels were equipped with a synchronous motor drive, two stages of gear reduction and a quick-change lathe gear box. Using this arrangement it was possible to obtain 63 different discharge rates varying from 0.15 to 18 cc/hour. Each of these flow rates could be increased by a factor of 6.25 by reversing the sprockets on the chain drive mechanism linking the transmission and feed screw.

Core samples 3 in. in length and 1 in. in diameter were extracted with a constant boiling mixture of methanol and benzene (40 per cent methanol) and molded in Lucite. A number of flow channels were drilled through the plastic mount into one end of the mounted sample in the manner illustrated in Fig. 7.

Separate channels were drilled for the oil and aqueous phases, although, to avoid complication only a single set is shown in the schematic drawing. The oil and aqueous phases were thus in contact only through interfaces of capillary dimensions. The necessity of a mixing section preceding the core sample under study, with the attendant difficulty and uncertainty of maintaining capillary contact between the sections, was thus avoided. In this manner, it was possible to measure separate pressure drops in the oil and aqueous phases at the extremeties of the core sample in the flow lines. A Lucite butt-piece containing sealed-in Saran flow lines was cemented to the mounted sample. Saran flow lines, Lucite reservoirs and glass stopcocks were used throughout the flow system in view of the highly corrosive nature of the tracer solution.

The pressure drop across the core sample was measured in each of the liquid phases using Moore Products Differential Pressure Transmitters. These instruments operate on a pneumatic null-balance principle and have a volumetric displacement, when completely liquid filled, of less than 0.05 cc. This small volume change is due to an uncertainty in relocation of the null position following a change in differential pressure.

Since the null position of the magnetic susceptibility apparatus was found to be dependent on the position of the transformer head relative to its surroundings, it was necessary to move the core sample and attached flow lines into the field of the transformer rather than moving the transformer itself. The core sample was held rigidly in a Lucite framework which fitted closely in grooves machined in flat Lucite stock. These guides were fastened securely to the framework of the transformer mounting.

In practice an initial voltmeter reading, obtained with the dry mounted core sample in the transformer gap, and a reading obtained after the core sample was saturated with the tracer liquid served as the basis from which further saturation values were obtained. The nature of the calibration curve, Fig. 3, and the data in Table 1 were presumed to verify the linear nature of the voltmeter response to the quantity of paramagnetic liquid in the air gap. A null was obtained on the voltmeter each time before the core sample was moved into the transformer field. Throughout these studies the criterion of flow equilibrium was chosen as the stability of differential pressure across the core sample.

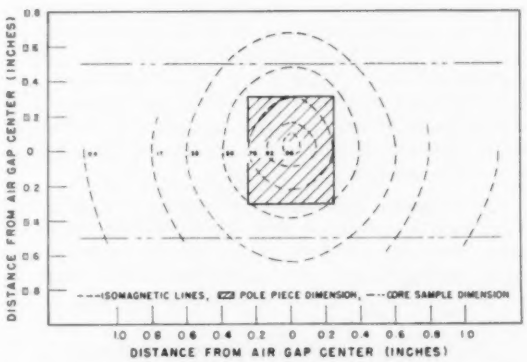

DISTANCE FROM AIR GAP CENTER (INCHES)
ISOMAGNETIC LINES, POLE PIECE DIMENSION, CORE SAMPLE DIMENSION
1.0 0.8 0.6 0.4 0.2 0 0.2 0.4 0.6 0.8 1.0
DISTANCE FROM AIR GAP CENTER (INCHES)

FIG. 4 — ISOMAGNETIC LINES AT THE AIR GAP CENTER IN A PLANE PERPENDICULAR TO THE PLANE OF THE TRANSFORMER.

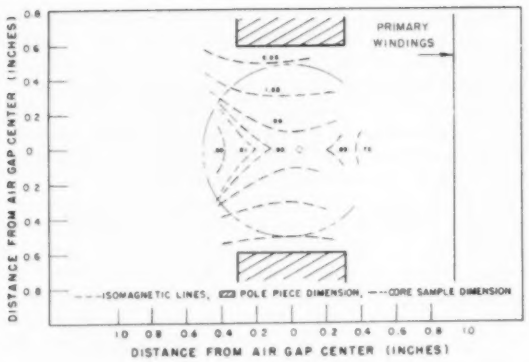

PRIMARY WINDINGS
DISTANCE FROM AIR GAP CENTER (INCHES)
---ISOMAGNETIC LINES, POLE PIECE DIMENSION, —CORE SAMPLE DIMENSION
DISTANCE FROM AIR GAP CENTER (INCHES)

FIG. 5 — ISOMAGNETIC LINES IN THE AIR GAP CENTER IN A PLANE CONTAINING THE TRANSFORMER.

The results of relative permeability studies on two core samples using the magnetic susceptibility apparatus for liquid saturation determination are reported herein. Pertinent data concerning these samples are given in Table 2. K_g is the single phase gas permeability uncorrected for slip effects, K_w is the single phase permeability to distilled water and k_{aq} is the single phase permeability to the tracer solution. The two phases used in this study were the mutually saturated liquids Soltrol "C" and the magnetic tracer solution. In each case the single aqueous-phase permeability was determined prior to two-phase flow studies. The relative permeability to each phase was determined at a number of points during both the aqueous-phase desaturation and the forced aqueous-phase imbibition. A total of three desaturation-imbibition cycles was completed on the sandstone core sample. A single cycle was run with the alundum sample. The two-phase dynamic flow studies are reported in the form of relative permeability curves in Figs. 8 and 9.

DISCUSSION

The performance of the magnetic susceptibility apparatus in the determination of liquid saturation when that liquid is uniformly distributed throughout the magnetic field is considered to be satisfactory. The graphical results shown in Fig. 3, where voltage indication was plotted versus relative concentration of tracer solution show excellent linearity. The maximum deviation from linearity was found to be 1.1 saturation per cent. All deviations were negative; the indicated saturation being lower than the value required by a linear calibration curve. Aside from this consideration the deviations are no greater than would be expected from the precision of the apparatus and are well within the limits currently considered acceptable for fluid saturation measurements.

The magnetic field studies presented in Figs. 4 and 5 indicate an adequate flux density concentration directly between the pole pieces of the magnet. The slight asymmetry of the isomagnetic lines about the air gap in Fig. 4 is due to flux leakage back to the transformer primary. This condition could, of course, be eliminated with no loss in sensitivity by constructing a transformer with a greater distance between the primary and the air gap. The flux leakage effects, however, contribute less to the non-uniformity of the magnetic field in the region occupied by a core sample than does the effect of the transformer pole piece area in concentrating flux lines near the center of the core sample. In addition, leakage effects would be expected to diminsh as reference planes nearer the transformer pole faces were selected.

From Fig. 5 it will be noted that a very minor portion (about 15 per cent) of the cross sectional area of the sample lies in a relatively low flux density portion of the magnetic field. Furthermore, in practice the distribution of tracer liquid throughout a portion of the field of the measuring transformer will tend to reduce the asymmetry of the field indicated by the pointwise study.

On the basis of these magnetic field studies it would appear that the distribution of liquid in the field of the measuring transformer can contribute significantly to the magnetic field strength only when the liquid distribution is varied along the length of a sample. In general, the variation in saturation encountered along a short core sample during multiphase flow studies is not large; seldom does it amount to more than 5 saturation per cent.

The magnetic susceptibility profile presented in Fig. 6 shows that the voltage decline is not appreciable until a point 0.75 in. from the center of the test cylinder is reached. The voltage indication is shown to be 43 per cent of the maximum reading when the transformer air gap is centered over the end of the test cylinder. The comparison between the magnetic susceptibility method and the low energy radiotracer method reported by Josendal, Sandiford, and Wilson[7] is quite good. These authors report a count decline over approximately ⅝-in. at the end of the test cylinder used in their work. Their data, however, indicate a slight decline, approximately 10 per cent, in the indicated activity over the ½ in. of the cylinder length preceding this region. Further indications from

TABLE 2 — PROPERTIES OF POROUS SAMPLES

Sample	Porosity (%)	Single-Phase Permeability (md) K_g	K_w	K_{aq}	Voltmeter Reading Dry Mounted Core
Alundum	25.3	133	110	109	−0.024
Aris Sand Outcrop	27.8	1080		1040	+ 0.083

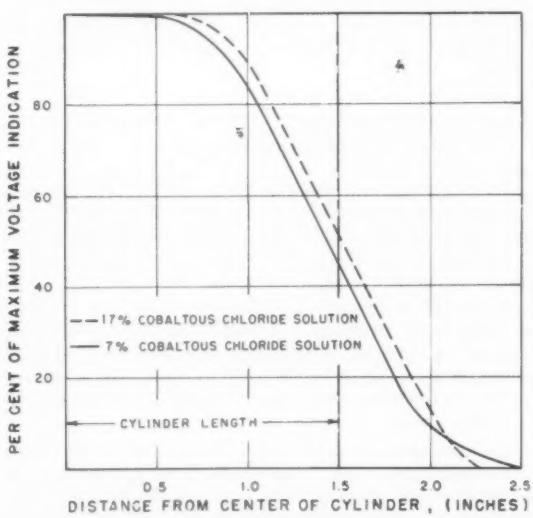


FIG. 6 — MAGNETIC SUSCEPTIBILITY PROFILE OF LIQUID FILLED HOLLOW CYLINDER.

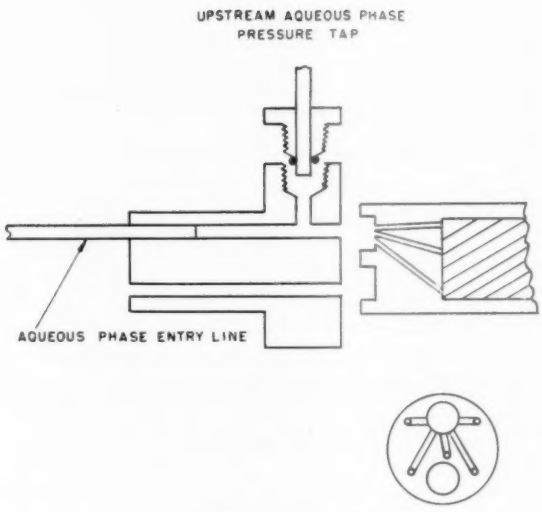


FIG. 7 — DIAGRAM OF TWO PHASE FLUID DISTRIBUTION HEAD.

their data show an activity decline to approximately 60 per cent of the initial activity at the end of the test cylinder.

In the magnetic susceptibility method, the slight spreading of the magnetic field of the measuring transformer as the quantity of magnetical material is increased introduces a factor not encountered in the radioactivity method. The dependence of field definition on the core sample saturation is not great, however, and may be no greater than the effect of self absorption, which is also saturation dependent, encountered in the use of radiotracers. The inability of the low energy radiotracer technique to define the end of the cylinder more exactly is somewhat surprising in that a better definition would be expected than for the magnetic susceptibility method.

On the basis of magnetic field studies reported it appears that the magnetic susceptibility method compares favorably with the radiotracer technique when low energy tracers are used. It should be emphasized that the radiotracer method and the magnetic susceptibility method for the external determination of saturation are the only volumetric methods reported to date. The resistivity method requires independent calibration for each core sample.[3] Linear absorption methods such as X-ray or gamma-ray absorption have been questioned[9,10] as to the uniqueness of their saturation indication when the core sample is undergoing successive saturation-desaturation experiments.

The simplicity of the magnetic susceptibility method is illustrated adequately by the schematic diagram shown in Fig. 2. With the present model of the transformer head, a slight drift in the voltage required to null the residual transformer unbalance necessitated nulling the instrument prior to each reading. Operation of the apparatus under conditions of controlled temperature and humidity was found to have no influence on the zero drift. The greatest utility of the magnetic susceptibility method would appear to be found in routine work where saturation profiles are not required. The data shown in Fig. 6 indicate that core samples as short as 1.5 in. could be used successfully. In the case of short core samples, saturation gradients due to fluid introduction and loss of capillary pressure at the output end of the sample are limiting factors.

The multiphase flow data reported herein using the magnetic susceptibility apparatus in the determination of liquid saturation are intended as a demonstration of the utility of the instrument. There are, however, several points of unusual behavior which warrant discussion. Relative permeability hysteresis was quite pronounced in the case of the alundum sample investigated and was accompanied by an inversion in the sign of the dynamic capillary pressure.* During the aqueous-phase desaturation portion of the flow cycle the dynamic capillary pressure exhibited a slight decrease with decreasing aqueous phase saturation, the absolute value at each point being lower than the corresponding value of the static capillary pressure. During the forced aqueous-phase imbibition portion of the flow cycle the pressure drop in the aqueous-phase was greater than that in the oil phase. Aqueous-phase permeabilities were greater at a given saturation in the imbibition (i.e., imbibition with respect to the aqueous phase) than those obtained in the desaturation portion of the flow cycle. Oil phase permeabilities, while exhibiting hysteresis effects, were normal in behavior. This behavior, together with the low oil-phase permeability at minimum aqueous-phase saturation, may be an indication of oil-wet surface properties for the particular alundum sample investigated. Low values of the dynamic capillary pressure as compared to static capillary pressure and apparent reversal of wetting properties of the two liquid-phases have been noted by other workers.[7]

Hysteresis was also noted in the relative permeability relationships for the natural sandstone core sample. In this case, however, aqueous-phase permeabilities decreased during the aqueous-phase imbibition portion of the flow cycle from those obtained during the first portion of the flow cycle. Dynamic capillary pressures were constant during any half flow cycle within the ability of the pressure sensing devices to resolve the small pressure differences between the oil and aqueous phases. Two repetitions of the flow cycle produced relative permeability values which are considered con-

*For the purposes of this paper the difference in pressure loss across the core sample in the oil and aqueous phases under equilibrium flow conditions is referred to as the dynamic capillary pressure. For a water-wetted porous material the dynamic capillary pressure is referred to as being positive in sign.

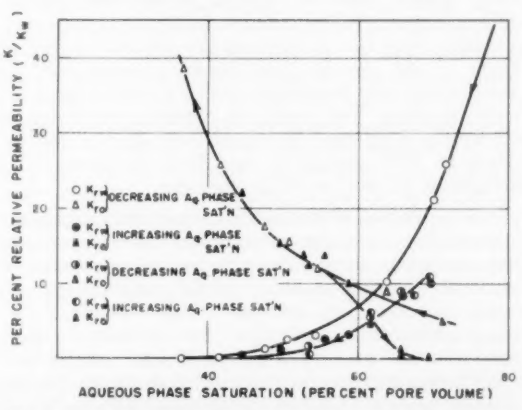


FIG. 8 — RELATIVE PERMEABILITY VERSUS AQUEOUS PHASE SATURATION SANDSTONE CORE SAMPLE NO. 2703.

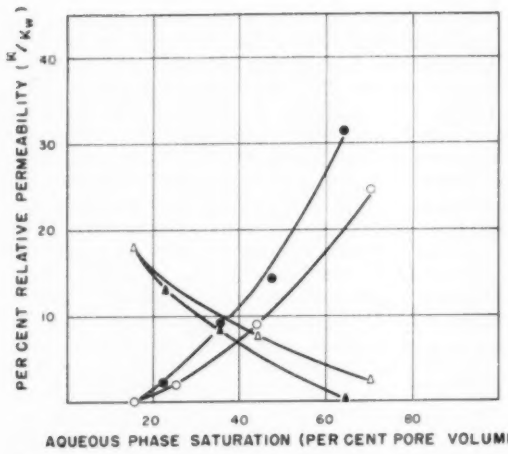


FIG. 9 — RELATIVE PERMEABILITY VERSUS AQUEOUS PHASE SATURATION ALUNDUM SAMPLE NO. 1427.

stant within the precision of the flow apparatus and magnetic susceptibility measurement. A slight decrease in the dynamic capillary pressure was noted during flow cycles following the initial aqueous-phase desaturation-imbibition cycle. There were, however, no corresponding differences in the relative permeability versus saturation relationships.

Use of the fluid distribution head illustrated in Fig. 7 makes possible the attainment of uniform saturation at a very short distance from the input end of the core sample. Microscopic examination indicated that less than ½ in. is required for "mixing" in the core sample. Maintenance of the required dynamic capillary pressure between the input phases should remove the possibility of "slug" flow encountered when the two fluids are introduced at the same pressure into a mixing head. Resolution of the change in sign of the dynamic capillary pressure in the case of the alundum sample is considered as further evidence that the distribution head functioned as anticipated.

In many cases the necessity for using a highly concentrated cobaltous chloride brine solution as the aqueous phase rather than a solution matching formation water in its composition may impose limitations on the applicability of the method. The natural sandstone sample used for relative permeability studies showed essentially no reduction in aqueous phase permeability from the air permeability value as shown in Table 2. In general, few complications should be encountered from swelling of the clay matrix using the tracer solution. The extent of changes introduced in the surface properties of natural core samples and the effects of such changes on the flow characteristics of the sample are not known at this time.

A more serious limitation on the use of the magnetic susceptibility apparatus concerns the use of core samples containing appreciable amounts of ferromagnetic materials. The Aris sandstone sample contained approximately the maximum amount of native magnetic materials which can be tolerated. The unbalance voltage indication for the dry unmounted core sample was 0.083 volts, approximately 30 per cent of the reading obtained when the sample was saturated with the tracer liquid. X-ray analysis of the core material indicated the presence of 0.7 per cent goethite.

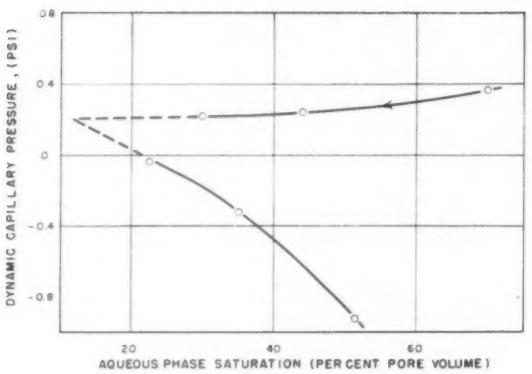


FIG. 10 — DYNAMIC CAPILLARY PRESSURE VERSUS AQUEOUS PHASE SATURATION ALUNDUM CORE SAMPLE NO. 1427.

CONCLUSIONS

A novel method of determining liquid saturation in a core sample using a magnetic tracer in the aqueous phase has been developed. The method is simple to operate and maintain and compares favorably with techniques currently practiced in the industry.

The utility of the method in the determination of liquid saturation values during oil-water relative permeability studies has been demonstrated. The method should be particularly applicable for routine studies.

ACKNOWLEDGMENT

Acknowledgment is made to the Magnolia Petroleum Co. for permission to publish the results of this work and to P. P. Reichertz who suggested the application of magnetic susceptibility techniques to the problem of fluid saturation determination in porous materials. Special thanks are due to C. W. Zimmerman for the construction of the transformer head used in these studies and for suggestions concerning the nulling circuit. The technical assistance of Karl Brockman, who performed much of the developmental work, is appreciated.

REFERENCES

1. Morse, R. A., Terwilliger, P. L., and Yuster, S. T.: *Producers Monthly* (1949), **11**, 19.
2. Boyer, R. L., Morgan, F., and Muskat, M.: *Trans.* AIME (1947), **170**, 15.
3. Morgan, F., McDowell, J. M., and Doty, E. C.: *Trans.* AIME (1950), **189**, 183.
4. Laird, A. D. K., and Putnam, J. A.: *Trans.* AIME (1951), **195**, 65.
5. Russell, R. G., Morgan, F., and Muskat, M.: *Trans.* AIME (1947), **170**, 51.
6. Coomber, S. E., and Tiratsoo, E. N.: *J. Inst. Pet.* (1950), **36**, 543.
7. Josendal, V. A., Sandiford, B. B., and Wilson, J. W.: *Trans.* AIME (1952), **195**, 65.
8. Brunner, E., and Mardock, E. S.: *Trans.* AIME (1946), **165**, 133.
9. Lipson, L. B.: *Trans.* AIME (1951), **192**, 375.
10. Geffen, T. M., and Gladfelter, R. E.: *Trans.* AIME (1952), **195**, 332. ★★★

USE of RADIOACTIVE IODINE as a TRACER in WATER-FLOODING OPERATIONS

J. WADE WATKINS
MEMBER AIME
BUREAU OF MINES
BARTLESVILLE, OKLA.

E. S. MARDOCK
MEMBER AIME
WELL SURVEYS, INC.
TULSA, OKLA.

T. P. 3894

ABSTRACT

The accurate evaluation of reservoir-performance characteristics in the secondary recovery of petroleum by water flooding requires use of a water tracer that may be injected into water-input wells and detected at oil-production wells to supplement data obtained from core analyses, wellhead tests, and subsurface measurements. Radioactive iodine has been used successfully as a water tracer in field tests to determine: (1) relative rates and patterns of flow of injected water between water-input and oil-production wells and (2) zones of excessive water entry into oil-production wells.

Laboratory evaluations of potential water tracers, previous tracer studies, the value of using a radioactive tracer, general field procedures, and the use of surface and subsurface instruments for the detection of the emitted gamma radiation, are summarized. Data from the field tests are presented graphically and discussed in detail.

It is concluded that the radioactive-tracer method, using radioactive iodine, may be used successfully to measure either the relative rates and patterns of flow or zones of excessive water entry into wells under conditions of comparatively rapid transit time between wells.

INTRODUCTION

Extensive use is made of data obtained from core analyses, wellhead tests, fluid characteristics, and subsurface measurements in evaluating the sweep efficiency of water injected into oil sands for the recovery of oil. Theoretical flow rates and patterns may be calculated from those data using radial-flow formulas, if it is assumed that the physical conditions in the productive formation are homogeneous. Unfortunately, homogeneous conditions rarely, if ever, exist in oil-productive formations. The use of a tracer that may be injected into an oil sand and detected quantitatively, or even qualitatively, at offsetting oil-production wells provides basic data that may be used in determining more accurately the subsurface rates and patterns of flow of injected water between wells than is possible by theoretical calculations based on assumed conditions. Consideration of the data obtained by using a water tracer assists in the application of remedial measures to water-input wells, such as plugging of channels, or selective plugging of highly permeable zones, thereby effecting a more uniform flood and a greater ultimate oil recovery.

A water tracer should have the following characteristics: (1) low adsorption on solid reservoir material; (2) high solubility in water; (3) low or negligible solubility in crude petroleum; (4) a wide range of solubility of compounds that may be formed by chemical reactions with ions present in reservoir rocks or waters; (5) high detectability in low concentrations by portable apparatus; and (6) general availability at low cost. Additional desirable characteristics are that the tracer should be nonhazardous in nature under normal working conditions and quantitatively detectable in the well bore, as well as at the surface.

Review of Previous Tracer Studies

The need for a water tracer has been recognized for many years. As far back as 1906, Dole[1] described the use of fluorescein in flow-rate studies made in France in 1901. In 1921, Ambrose[2] discussed in detail the use of organic and inorganic dyes, chlorides, nitrates, and other anions, lithium salts, and the Slichter electrical

[1]References given at end of paper.

Manuscript received in Petroleum Branch office Jan. 11, 1954. Paper presented at Annual AIME Meeting in New York City, Feb. 13-17, 1954.

method for tracing the underground flow of oil-field waters. More recently, several articles on the use of water tracers in oil production have been published. Sturm and Johnson[2] presented the results of field tests in Pennsylvania oil fields in which fluorescein, chlorides, and surface-active agents were employed as water tracers. Carpenter and others[4] discussed several field tests in Mid-Continent oil fields in which boron, as borax and boric acid, was used as a tracer. Quite recently, Garst and Wood[8] presented the results of experimental field tests in which stable (not radioactive) copper and iodide salts were used as flood-water tracers. In 1945, Plummer[6] discussed the general subject of water tracers, including many of those previously mentioned, as well as radioactive tracers.

Archibald[7] reported the results of surface flow tests made in 1949 in which radioactive iodine was used as a tracer in field tests. In 1950, Coomber and Tiratsoo[9] published the results of laboratory flow tests in which radioactive iodine was used as a tracer in the oil phase in laboratory flow tests. Several patents have been issued that bear on the injection of radioactive materials into water-input and oil-production wells for various purposes, such as those issued to French[9] in 1947, describing the use of a radioactive gas, and Hinson[10] in 1951, describing the use of radioactive gases, liquids, and solids for determining flow rates and patterns of fluids injected into subsurface strata. A patent also has been issued to Bond and Savoy[11] bearing on the use of acetylene as a tracer gas in both gas and water-injection operations.

Despite the attention evidenced in the subject by the above-cited references, nothing has been published concerning the successful or attempted use of radioactive water tracers in field secondary-recovery operations.

LABORATORY EVALUATION OF TRACERS

In July, 1947, a water-tracer study was started in the Bartlesville laboratories of the Bureau of Mines, but the study was temporarily discontinued in January, 1948. Several tracer substances were considered during this period, and field tests were made using the ammonium ion as a tracer. The results, however, were unsatisfactory because of the high concentration of ammonium ion in many produced waters. Laboratory tests were made with fluorides with inconclusive results. At the time the study was discontinued, the expressed opinion of the chemist in charge of the work was that radioactive tracers appeared to offer the greatest promise.

A radiochemical laboratory was completed, and the tracer study was resumed in 1951. Numerous selected substances were tested to determine their adsorption characteristics by passing "slugs" of the material in water through long, consolidated sandstone cores, sealed in plastic, and measuring quantitatively the tracer in the effluent fluid. Substances for tests were selected primarily on the basis of the solubility of their common compounds and secondarily on the basis of expected low adsorption characteristics. Fluorescent dyes were among the tracers tested and, like several other substances, were found to be highly adsorbed in the cores. It was concluded that fluorescent dyes, such as fluorescein, were useful for tracers only when it was known or suspected that channels or fractures existed between wells. One of the materials selected as a potential water tracer was iodine as the iodide ion. All of the laboratory evaluation tests were made with stable rather than radioactive isotopes, and standard methods of quantitative analysis were used.

It was believed that radioactive tracers would be superior to stable ones because: (1) they may be easily detected in low concentrations; (2) they may be detected by subsurface instruments if the emitted radiation is gamma or hard beta; and (3) the necessary radiation-detection equipment may be made portable.

Consequently, instruments were assembled, and the necessary permission was obtained from the Atomic Energy Commission to make field tests using radioactive iodine (iodine 131) as a water tracer.

GENERAL FIELD PROCEDURES

All field radioactive-tracer tests described herein were made by the Bureau of Mines in cooperation with Well Surveys, Inc., Tulsa. Under the existing cooperative agreement the Bureau of Mines has procured and injected the radioactive iodine used as the water tracer and made all surface measurements of radioactivity. Well Surveys, Inc., has made all subsurface gamma-ray and neutron logs and radioactivity input-profile logs on water-input wells.

Before a location was selected for a field tracer test, all available information concerning the wells and reservoir characteristics and performance was evaluated. Injection rates and pressures on water-input wells were examined to determine anomalous conditions thereby indicated, such as abnormally high injection rates or low injection pressures.

The first step in the field tests was to obtain a water-input profile on the well selected for tracer injection by the use of the Well Surveys, Inc., radioactivity input-profile method. If caliper measurements were not available on the holes used in the tracer tests, those measurements were made (especially if the sand had been shot) as part of the profile measurement and to assist in the interpretation of radioactivity logs.

Standard gamma-ray and neutron logs were made on the input well as well as on all production wells at which the tracer might appear, using conventional gamma-ray and neutron ionization-chamber instruments. This equipment is the same as that used commercially by the licensees of Well Surveys, Inc. These logs correlated the lithology of the formation with core-analysis data and provided the necessary background information for the tracer surveys.

If the data available indicate that the water is passing rapidly from the input to the production wells, it may be advisable to make a dye-tracer test before injecting the radioactive tracer. The purpose of this test in the Bureau of Mines field work was to determine the approximate transit time from the water-input well to the production wells. This information permitted scheduling arrival of the gamma-ray logging crew at a time that would permit locating the subsurface logging instrument in the borehole of the production well at which the tracer first appeared without excessive waiting. Also, the positive appearance of dye tracer at production wells confirmed the existence of channels and simplified calculation of the quantity of tracer needed and the optimum injection time of the tracer slug.

Both the dye tracer and the radioactive iodine tracer were injected into the head of the input well while normal injection rates and pressures were maintained.

The injection device employed a chamber containing a free-floating piston, which was moved hydraulically, confining all contamination to the chamber and piping manifold. The usual injection rate of tracer was about 3.8 liters (1 gal.) in 15 minutes.

Radioactivity of the fluids produced from all production wells at which the tracer might appear was continuously monitored by the use of gamma-sensitive Geiger-Mueller tubes inserted vertically into each wellhead or lead line. The tubes, made in the Bureau of Mines radiochemical laboratory at Bartlesville, were 1¼-in. in diameter, had an effective bismuth cathode length of about 12 in., and were filled with an argon-ethyl formate gas mixture. The tubes were equipped with a standard 1½-in. pipe-thread adapter that permitted screwing them directly into a pipe fitting. The output pulse from each tube went into a counting-rate meter, and the signal from the counting-rate meter was fed into a strip-chart recorder. Thus, a continuous recording was made of the radioactivity background of produced fluids at production wellheads.

Liquid samples were taken at random intervals from each of the wellheads until the recorded radioactivity increased significantly above background. Thereafter, samples were taken at frequent intervals. The radioactivity of the water separated from the liquid samples was measured with a conventional dipping-type Geiger-Mueller tube and scaler to provide more accurate measurements.

Before the anticipated time for the tracer to reach the borehole of the first production well the subsurface gamma-ray logging instrument was positioned opposite the productive formation in that well. Numerous gamma-ray logs of the well borehole were made as the radioactive tracer was produced into the hole with water. In this manner, the zones through which the water was moving most freely were clearly defined.

POTENTIAL HEALTH HAZARDS FROM THE USE OF RADIOACTIVE MATERIAL

Although some hazard to health always is present when radioactive material is used, careful and proper handling techniques and rigid personnel monitoring reduced the potential health hazard in field operations to a negligible level. The greatest concentration of radioactive material handled was at the water-input well. As soon as the tracer entered the input well, it was diluted to a great extent before its reappearance.

The use of proper techniques, adequate shielding, film badges and pocket chambers, and constant monitoring with survey meters guarded field personnel against overexposure to radiation. The quantities of radioactive iodine handled in laboratory and field tests ranged from 1 to 250 millicuries. In no field test made was the radiation level of containers in which produced brine carrying radioactive tracer was stored, above tolerance.*

The maximum permissible level of iodine 131 in the body, with maximum concentration in the thyroid, is given by the National Bureau of Standards[12] as 0.3 microcurie, and the maximum permissible level in liquid media for continuous exposure as 3×10^{-5} microcuries/ml. No hazardous concentration of iodine 131 was available for human or livestock consumption in any of the field tests, as produced brine containing greater than the cited permissible concentrations was routinely diluted in surface storage ponds to a low level of concentration. Although the contamination of surface equipment by radioactive iodine was guarded against, the short half-life (eight days) was considered an advantage from the standpoint of the rapid decay of active material. However, the comparatively short half-life limits the use of radioactive iodine as a flood-water tracer to situations when passage of injected water between wells may be expected within about four half-lives, or four to five weeks.

RESULTS OF FIELD TRACER TESTS

Test A

Field tracer test A was made on an inverted five-spot where excessive water was produced at two wells and an undesirably high ratio of water to oil was produced at the other two wells. Production data indicated that there was a direct channel from southwest to northeast, connecting the input well with the two production wells having the highest water-oil ratios. Fluorescein was injected into the input well to confirm the presence of this channel and to establish transit time between wells. No fluorescence was detected, however, in water from any of the production wells over a period of two weeks. Radioactive tracer tests then were made by injecting radioactive iodine in quantities of 1, 25, and about 85 millicuries* in three successive tests to determine the optimum quantity of tracer material needed.

Slight increases in the radioactivity of water produced from one of the wells were observed in each of the three tests. However, these increases were small, of short duration, and were not proportional to the quantities of radioactive material injected. In no instance was it possible to get the gamma-ray logging instrument into a well soon enough to detect any significant increase in the radioactivity of the water entering the well. One of the production wells in the inverted five-spot had not been reworked when the flood was started and did not have pipe cemented at the top of the production formation, and the pipe was not continuous throughout the borehole. It was concluded that most of the tracer was lost through that well to upper, permeable formations, through which the water was escaping from the immediate vicinity. Figures on fluids injected and produced tended to confirm this conclusion. Injectivity-index data obtained indicated that the loss of water may have been caused in part by operation of the project at pressures high enough to increase the bypassing potential between wells.

Test B

Field tracer test B was made in Nowata County, Okla., on a water-flooding project that was near the economic limit of production by conventional water flooding. Production was from the Bartlesville sand, which in the area of the test is 510** ft deep. The wells involved in the test were completed with about 45 ft of oil sand exposed.

*Tolerance dose usually is expressed as 0.3 roetgen equivalent physical per week, or 7.5 milliroentgen equivalent physical per hour, based on a 40-hour work week.

*One millicurie is equal to 3.7×10^{7} disintegrations per second. All activity values given in this paper are corrected for decay to injection time.

**All depths given are from the surface.

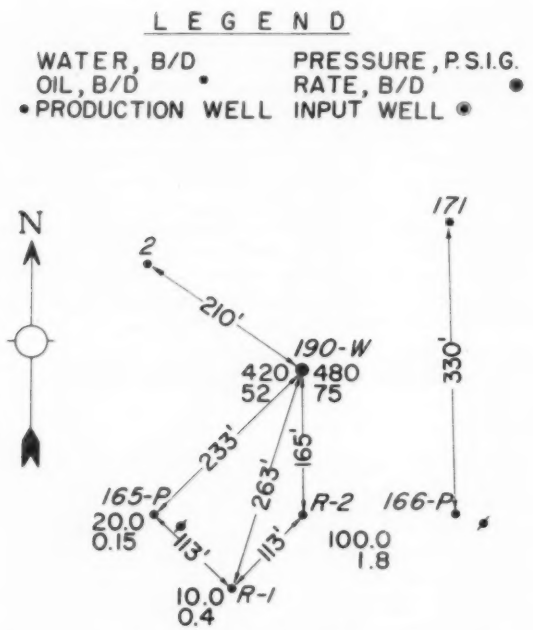


FIG. 1 — LOCATIONS OF WELLS IN FIELD RADIOACTIVE-TRACER TEST B, NOWATA COUNTY, OKLA.

Fig. 1 shows the locations of, and distances between, wells involved in the test and pertinent wellhead data. Well R-2 had been drilled a few months earlier, midway between two water-input wells, and Well R-1 midway between a water-input and an oil-production well to determine the residual-oil saturation of the sand. As indicated on Fig. 1, the daily production from Well R-1 at the time of the tests was 10.0 bbls of water and 0.4 bbl of oil, or a water-oil ratio of 25:1; from Well R-2, 100.0 bbls of water and 1.8 bbls of oil, or a water-oil ratio of 56:1; and from Well 165-P, 20.0 bbls of water and 0.15 bbl of oil, or a water-oil ratio of 130:1. The excessive water production from wells R-1 and R-2 suggested that there was channeling of water from water-input Well 190-W. Flow-rate tests were made on Well 190-W by the operating company, using anchor packers to isolate the zones tested. The results of those tests indicated that most of the injected water was leaving the well at a depth of approximately 520 ft. As 2-in. tubing was cemented in that well, it was not possible to obtain gamma-ray logs or to make radioactivity input profiles of the well with the equipment then available. However, subsequent input-profile tests by the operating company confirmed the information obtained from the flow-rate tests.

A solution containing 8 oz of fluorescein was injected into input Well 190-W over a period of 15 minutes in about 0.36 bbl of water. Dye was detected in the water produced from Well R-2 after about 11 hours, or after the injection of approximately 16 bbls of water into Well 190-W and the production of approximately 28 bbls of liquid from Well R-2. No fluorescence was detected in the water produced from wells R-1 and 165-P. Production of the dye at Well R-2 confirmed the presence of the suspected channel between wells.

A solution containing approximately 87 millicuries of iodine 131 was injected into input Well 190-W over a period of 15 minutes in about 1 bbl of injection water. The rate of water injection into Well 190-W had been increased since the dye-tracer test. Increased radioactivity was detected in the well bore of Well R-2 2¾ hours after tracer injection, during which time 11 bbls of water was injected into Well 190-W. From the height of the radioactive liquid in the well tubing when the first log was made, it appeared that the tracer had reached the well bore after an elapsed time of about two hours. Increased radioactivity was detected at the surface in the liquid produced from Well R-2 4½ hours after tracer injection, during which time about 19 bbls of water was injected.

The increased radioactivity of water produced into Well R-2, as compared to the gamma-ray background, is shown in Fig. 2. As indicated, the recorded increase in gamma radiation, after three hours and 15 minutes (log 2) showed that water was coming into the hole in quantity at a depth of 520 ft. Radioactivity was high from 497 to about 520 ft, declined, and was high again from about 491 to 494 ft, or just under the pipe seat.

Subsequent logs made at 30-minute intervals (logs 3 and 4) showed that the activity of the water produced into the hole at a depth of 520 ft decreased while that of the water produced at about 491 ft increased. Also, in the later logs it was shown that the principal zones of water entry within the 497 to 520-ft zone were at about 506 and 514 ft. Log 5, made the following day, showed that a greater zone of activity was present behind the pipe, at about 487 ft, than at any other point in the well. This indicates that the upper zone of transmission may have been at that vertical point and that some residual radioactivity was present because of partial adsorption.

From the time that increased radioactivity was detected in water produced from Well R-2, the radioactivity of samples of water obtained at that wellhead increased sharply and reached a peak at about seven hours after tracer injection, as shown in the plot of radioactivity in Fig. 3. Radioactivity of the produced water decreased rapidly during the next three hours, and more gradually thereafter. Samples of the water

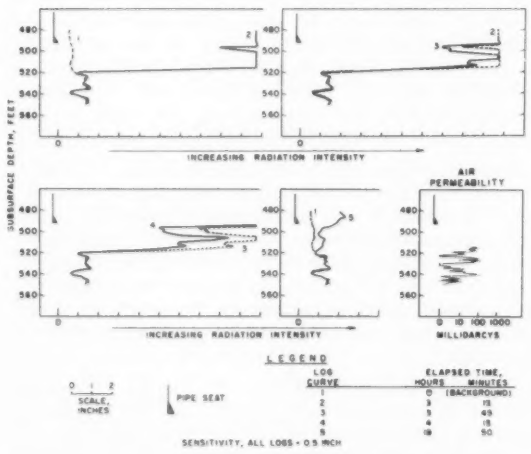


FIG. 2 — GAMMA-RAY BACKGROUND, WATER-PRODUCTION, AND AIR-PERMEABILITY LOGS, PRODUCTION WELL R-2, FIELD RADIOACTIVE-TRACER TEST B, NOWATA COUNTY, OKLA.

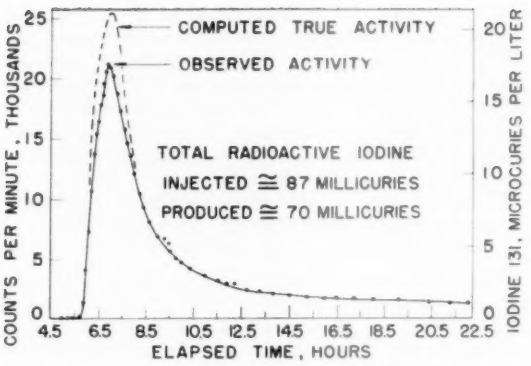


FIG. 3 — RADIOACTIVITY ABOVE BACKGROUND OF WATER FROM PRODUCTION WELL R-2, FIELD RADIOACTIVE-TRACER TEST B, NOWATA COUNTY, OKLA.

produced from Well R-2 still had some significant activity above background 12 days after tracer injection.

All determinations of the radioactivity of produced water were made by counting liquid samples, using a conventional scaling unit and a bismuth-cathode tube having a high sensitivity to the gamma radiation from iodine 131. Integration of the activity detected in water produced from Well R-2 showed that approximately 70 millicuries, or about 80 per cent of the total iodine injected entered that well. The higher observed radioactivity values determined on samples of produced water, as shown on Fig. 3 from about 11,000 to 21,000 counts per minute, were subject to error because the resolving time of the counter did not permit counting all of the pulses in that range. Corrections made for counts missed, based on the known resolving time of the counter, were added to the observed radioactivity and plotted as shown to indicate the true radioactivity of the samples.

A slight increase in radioactivity of the water produced from Well R-1 was detected about 72 hours after tracer injection; however, the peak was low in magnitude, and the rate of radioactivity decrease was much more rapid than that of the water from Well R-2. No significant increases in radioactivity were detected in the water produced from any of the other four wells likely to have been affected. At the time R-1 was relogged, several hours after the slight radioactivity increase was observed, the radioactivity had declined in the sand section to a point where no increase above background was detectable.

The data obtained show that water was transmitted directly from input Well 190-W to production Well R-2 through one or two channels at a depth of about 520 ft. Water also was being produced into the well from behind the pipe, at the pipe seat, possibly through a zone at a depth of about 487 ft. The production of the water from two zones into the production well suggested the presence of a vertical fracture in the formation between the wells. Knowledge of such a fracture would be important in planning remedial work, such as selective plugging. The fact that some tracer was found in water from Well R-1 indicates that the channel from 190-W to R-2 may have been continuous, either from 190-W to R-1 over a distance of 263 ft, or from 190-W to R-1 via R-2 over a distance of about 278 ft.

TEST C

The third field radioactive-tracer test was made on an inverted, elongated, irregular five-spot in a shoestring field in Anderson County, Kans., where oil was produced from a Bartlesville sandstone. The top of the production formation ranged in depth from 774 to 791 ft, and sand thicknesses ranged from 25 to 42 ft in the immediate vicinity. The locations of, and distances between, wells affected by the test and pertinent wellhead data are shown in Fig. 4. Production Well G-17 was drilled as a core-test well and later was utilized as a production well. Production wells H-16 and F-16 were old wells; H-14 and F-14 and input Well G-15 were new wells. Excessive water was being produced at wells H-16 and F-16 and, to a lesser extent, at wells H-14 and F-14.

The rate of water production at Well H-16 alone was greater than the rate of injection into input Well G-15; therefore, this input well alone could not be considered responsible for the excessive water production. Wellhead injectivity-index tests were made and pressure-decline rates were determined on several water-input wells in the general area. The results of those tests indicated that the performance of Well G-15 was abnormal and that this well might be the major cause of the high water-production rate at Well H-16, as well as at the surrounding wells. The fact that Well G-17, almost in a direct line between input Well G-15 and Well H-16, did not produce water in appreciable quantity led to the conclusion that a channel, or zone of very high permeability existed between wells.

A dye-tracer test was made to confirm the existence of such a zone and to establish transit time between wells. A solution containing 8 ozs of fluorescein was injected into input Well G-15 over a period of 15 minutes, with approximately 0.7 bbl of water. Liquid samples were obtained from all five production wells each two hours for the next three 24-hour periods and each day for the following week, and the separated water was examined for fluorescence. The first fluorescence was detected in water produced from Well H-16 58 hours after tracer injection, during which time about 162 bbls of water had been injected into Well G-15 and about 261 bbls of liquid had been produced from Well H-16. The fluorescence of the water had a peak intensity of 0.5 ppm and was present for at least two weeks. The first fluorescence was detected in water produced from Well F-16 after about seven days at a

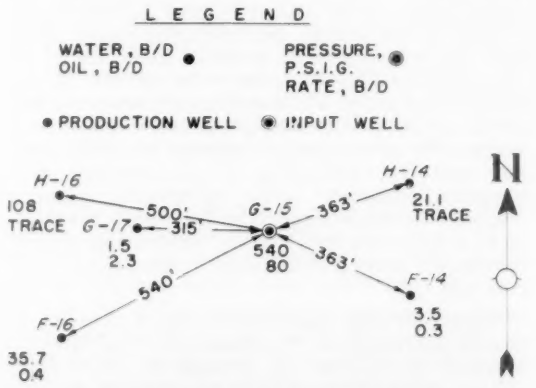


FIG 4 — LOCATION OF WELLS ON FIELD RADIOACTIVE-TRACER TEST C, ANDERSON COUNTY, KANS.

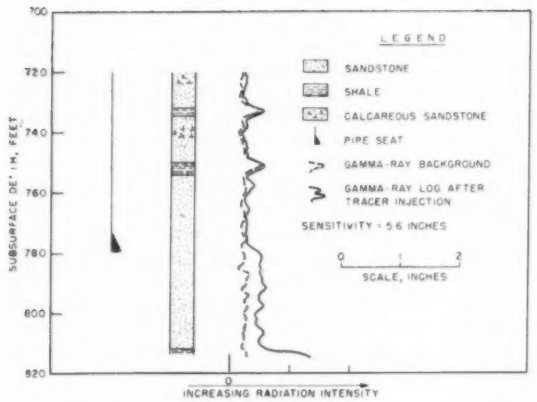


FIG. 5 — LITHOLOGY, GAMMA-RAY BACKGROUND, AND INPUT-PROFILE LOGS, WATER-INPUT WELL G-15, FIELD RADIOACTIVE-TRACER TEST C, ANDERSON COUNTY, KANS.

maximum concentration of less than 0.5 ppm and fluorescence in that water decreased rapidly. No fluorescence was detected in water produced from wells H-14, F-14, and G-17.

After completion of the dye-tracer tests, standard gamma-ray and neutron logs were made on all wells involved in the tracer test. A radioactivity input profile also was determined on input Well G-15. The lithology of the hole as interpreted from standard gamma-ray and neutron logs and a log of the input profile are shown in Fig. 5. Increased radioactivity at the principal points of exit of water from the well bore is shown as compared to the gamma-ray background caused by naturally radioactive material in the formation. Although upper sections of the formation are shown to be taking some water, the principal point of water exit is shown to be at the bottom of the hole, or from about 811 to 814 ft. Minor zones of water exit were indicated at about 798 and 807 ft.

After the input profile was determined, a solution containing 44 millicuries of iodine 131 was injected into input Well G-15 over a period of 15 minutes with approximately 0.8 bbl of water. The injection rate into Well G-15 at that time was 88 bbls daily, as compared to 67 bbls daily at the time of the dye-tracer test.

Wells H-16, F-16, and H-14 were monitored continuously in the manner previously described to determine the radioactivity of produced fluids during the next eight days. No instruments were available for use in wells F-14 and G-17. However, little water was produced at those wells during the tracer test. Liquid samples were taken from all wellheads at random intervals until the radioactivity of the produced fluids increased significantly above background; thereafter samples were taken regularly at frequent intervals. At no time during the tests was any significant increase in radioactivity noticed in the water produced from wells F-14 and G-17.

Gamma-ray logs reproduced in Fig. 6 illustrate the rate of production of the tracer into Well H-16, as indicated by increases in radioactivity above background. The first increase in radioactivity of produced water at the surface was observed about 32 hours after tracer injection. Transit time of the fluid from the well bore to the surface was calculated to be about two hours and 48 minutes; consequently, the first entry of radioactive water into the well bore probably occurred after about 29 hours. However, the first log showing entry of radioactive material into the well bore was not made until 49 hours and 20 minutes after tracer injection. The difference in transit time between wells with dye and radioactive tracers in this instance, as well as in test B, is believed to have been caused primarily by increases in injection rates and secondarily by partial adsorption of the fluorescent dye.

The zones of water entry into Well H-16 on the first log made after tracer injection (log 2) were at 815 ft and at 823 ft. As shown in logs 3, 4, and 5, the radioactivity at 815 ft decreased, and the radioactivity of the water coming into the hole at the 823-ft level and at about 829 ft increased. These data show that water was entering the hole through three zones, two of which were within 9 ft of the bottom of the well.

The first log of Well F-16, after surface detection of a radioactivity increase, was made 118 hours and 30 minutes after tracer injection. Surface radioactivity recordings indicated that the radioactive tracer was present about 10 hours earlier. Although some slight indications of increased radioactivity were logged at depth intervals of 792-4 and 803-6 ft, repeated logs on this well showed that the greatest amount of the tracer material entering the well was coming in at the bottom, or at about 830 ft as shown in Fig. 7.

The radioactivity of the fluids produced from wells F-16, H-16, and H-14, as recorded at the surface, is illustrated in Fig. 8. The first increase in recorded radioactivity of fluids from Well H-16 occurred about 32 hours, and a peak of activity was reached about 46 hours after tracer injection. A second well-defined peak was recorded 78 hours, and a third, lower peak about 108 hours after tracer injection. The appearance of these peaks of activity at the surface correlates fairly well with the maximum intensity of detected subsurface radioactivity from the three zones of maximum production.

Again, in the recorded radioactivity of Well F-16, three peaks of less magnitude may be seen. The first occurred after 108 hours, the second after 132 hours, and the third after 170 hours' elapsed time.

Although the recorded radioactivity of fluids produced from Well H-14 also shows three peaks, anomalies are exhibited as follows: (1) the peaks are in

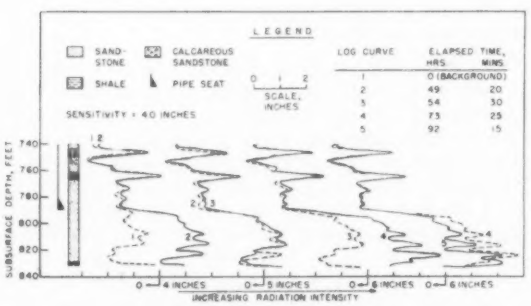


FIG. 6 — LITHOLOGY, GAMMA-RAY BACKGROUND, AND WATER-PRODUCTION LOGS, PRODUCTION WELL H-16, FIELD RADIOACTIVE-TRACER TEST C, ANDERSON COUNTY, KANS.

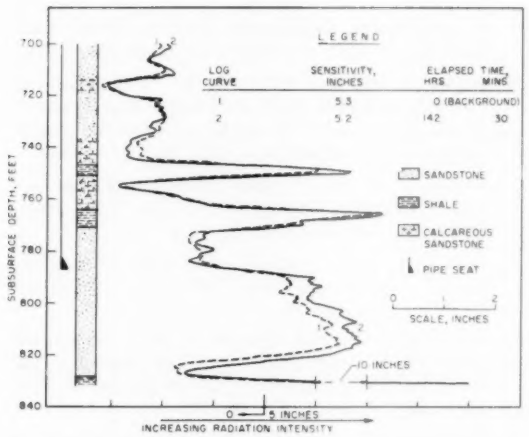


FIG. 7 — LITHOLOGY, GAMMA-RAY BACKGROUND, AND WATER-PRODUCTION LOGS, PRODUCTION WELL F-16, FIELD RADIOACTIVE-TRACER TEST C, ANDERSON COUNTY, KANS.

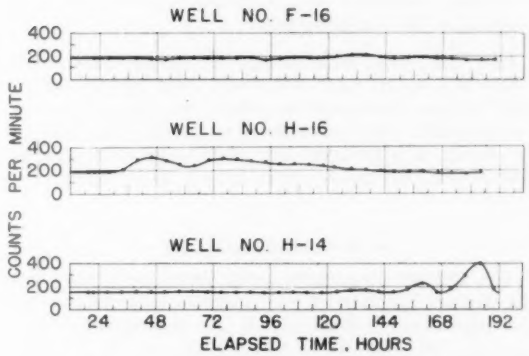


FIG. 8 — RECORDED RADIOACTIVITY OF WATER FROM PRODUCTION WELLS, FIELD RADIOACTIVE-TRACER TEST C, ANDERSON COUNTY, KANS.

reverse order of magnitude to those obtained on records of the radioactivity of water produced from other wells; (2) the maximum activity recorded was much higher than that on the other two wells; and (3) the decrease of radioactivity in each instance was quite rapid.

The first peak was recorded after 134 hours, the second after 158 hours, and the third after 182 hours' elapsed time. The high magnitude and short duration of the activity recorded suggests that concentrated slugs of radioactive water were produced at intervals from three highly permeable zones. It is conceivable that the production of tracer slugs of increasing magnitude might occur if the zones of transmission had different permeabilities and thicknesses. It was not possible to obtain subsurface radioactivity logs in this well after the appearance at the surface of increased radioactivity.

Conclusions drawn from the third field test follow: (1) excessive water production in the wells considered was caused by the rapid travel of injection water through highly permeable zones, sand-shale contacts, or fractures near the bottoms of the completed wells; (2) the zones were continuous between wells and the zone of maximum water transmission was shown at or near the bottoms of the wells, with other zones indicated within 10 ft of the bottoms; (3) plugging back of wells, or selective plugging of the "loose" zones should materially decrease water production and increase oil production on the property; and (4) the peaks of surface recorded radioactivity were caused by the production of water, in varying quantities, through three zones of high permeability or channels having different capacities for water transmission.

CONCLUSIONS

General conclusions concerning the practicability of using a radioactive water tracer and the particular advantage of using radioactive iodine may be drawn from the results of the field tests performed to date, as follows:

(1) The radioactive water-tracer method is considered to be superior to a method using a stable tracer because the radioactive method may be used successfully:

(a) To locate vertically channels or highly permeable zones extending between wells within an oil-productive formation; and

(b) To define horizontally the areas of greatest comparative permeability to water within a field or lease.

(2) Radioactive iodine is a satisfactory tracer material to use in the method because it has most of the characteristics of an ideal water tracer, namely:

(a) The loss of iodine, as iodide, through adsorption on reservoir solids is low as compared to other potential tracer substances;

(b) Iodide remains preferentially soluble in water and insoluble in oil during the progress of a tracer test;

(c) The possibility of an insoluble iodine compound being formed and precipitated in the oil-productive formation with consequent loss of tracer material is remote;

(d) The cost of using radioactive iodine as a tracer in the quantities normally required is not prohibitive;

(e) Radioactive iodine is readily and routinely available through the Atomic Energy Commission if adequate facilities for handling and personnel monitoring are available by the user; and

(f) Radioactive iodine, because of the intensity of the emitted gamma radiation, is easily detectable in small concentrations, both on the surface and in bore holes, by the use of standard, portable instruments.

(3) The short half life of artificially radioactive elements gives them a great advantage over the long-lived naturally radioactive elements previously considered for this and similar tracer applications because:

(a) The formations are not permanently contaminated and accordingly standard radioactivity well logs may be run on the wells involved in a tracer survey after a relatively short waiting period, and

(b) The personnel hazard is greatly reduced because any contamination of surface equipment re-

maining following decontamination procedures will decay to the vanishing point.

(4) The only disadvantage of using radioactive iodine as a water tracer is the very short half-life which limits its use to conditions where the transit time of injected water between wells is no longer than four to five weeks. It is believed that other radioactive isotopes may be used for conditions of longer transit times.

ACKNOWLEDGMENT

The authors are grateful to the following persons for constructive criticism of, and suggestions pertaining to, this paper: J. H. Buck and R. K. Schumacher, Well Surveys, Inc., and D. B. Taliaferro and R. Vincent Smith, Bureau of Mines. The cooperation of supervisory and field personnel of the Deep Rock Oil Corp. and Sinclair Research Laboratories, Inc., in providing properties, facilities, and data for the study, especially is acknowledged.

REFERENCES

1. Dole, R. B.: "Use of Fluorescein in the Study of Underground Waters," Water Supply Paper 160, U. S. Geological Survey, (1906) 76.
2. Ambrose, A. W.: "Underground Conditions in Oil Fields," *Bull.* 195, Bureau of Mines, (1921) 106.
3. Sturm, P. W., and Johnson, W. E.: "Field Experiments with Chemical Tracers in Flood Waters," *Producers Monthly* (December, 1950) **15**, 11.
4. Carpenter, P. G., Morgan, T. D., and Parsons, E. D.: "Boron Compounds Used as Water-Flood Tracers," *World Oil* (April, 1953) **136**, No. 5, 214.
5. Garst, A. W., and Wood, B. B.: "Field Tests of Copper and Iodide Salts as Water Flood Tracers," presented, Seventh Tri-Sectional Meeting, Amer. Chem. Soc., Bartlesville, Okla., Oct. 17, 1953.
6. Plummer, F. B.: "Tracing Flow of Fluids and Gases Beneath Ground," *Oil and Gas Jour.*, (Sept. 29, 1945) **44**, No. 21, 141.
7. Archibald, R. S.: "Radioactive Tracers in Flow Tests," *Jour. Boston Soc. Civil Eng.*, (1950) **37**, 49.
8. Coomber, S. E., and Tiratsoo, E. N.: "The Application of Radioactive Tracer Techniques to the Study of the Movement of Oil in Sands," *J. Inst. Pet.*, (September, 1950) **36**, 543.
9. French, R. W., Jr.: "Method for Determining Fluid Conductance of Earth Layers," U. S. Letters Patent 2,429,577, Oct. 21, 1947.
10. Hinson, H. H.: "Method of Determining Path, Rate of Flow, Etc., in Earth Strata," U. S. Letters Patent 2,560, 510, July 10, 1951.
11. Bond, Donald C., and Savoy, Michael: "Method of Studying Earth Formations Employing Acetylene as a Tracer Gas," U. S. Letters Patent 2,589,219, Mar. 18, 1952.
12. "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water," Handbook 52, National Bureau of Standards (1953). ★ ★ ★

SOLUTION of the EQUATIONS of UNSTEADY STATE TWO-PHASE FLOW in OIL RESERVOIRS

W. J. WEST
W. W. GARVIN
CALIFORNIA RESEARCH CORP.
LA HABRA, CALIF.

J. W. SHELDON
SCIENTIFIC COMPUTING SERVICE
INTERNATIONAL BUSINESS MACHINES CORP
NEW YORK, N. Y.

T. P. 3892

SUMMARY

One of the most important problems of reservoir mechanics is the prediction of the behavior of a gas and oil producing reservoir for a variety of production programs. In the absence of a knowledge of the behavior of even idealized systems, it has been difficult, if not impossible, to determine which production program would yield maximum economic recovery. The problem was formulated[1] mathematically many years ago, but a solution of the equations had never been obtained because of their extreme complexity. The solution of the problem became possible, however, with the advent of modern computing machines.

This paper describes a digital method of solving the problem and discusses some of the results which have been obtained to date. The IBM Type 701 Electronic Data Processing Machines located at IBM's New York Scientific Computing Service were used successfully to perform the computations.

The flow of gas and oil through a reservoir can be described mathematically by two second-order, nonlinear partial differential equations which must be solved simultaneously. All derivatives were replaced by finite differences to bring the equations into a form suitable for digital calculations. A number of finite difference formulations were investigated and one form was found which resulted in stable, convergent solutions. This form was used to obtain solutions for both radial and linear systems producing by solution gas drive.

The results presented in this paper are: (a) saturation profile within the hypothetical reservoir versus time, (b) pressure profile within the hypothetical reservoir versus time, (c) gas-oil ratio versus cumulative recovery, and (d) ultimate recovery. The saturation profile clearly shows the effect of critical gas saturation. The saturation near the well bore drops quickly to the critical gas saturation and remains essentially at that value until the remainder of the reservoir also has dropped to the critical gas saturation. The pressure profile shows a smooth variation of pressure across the reservoir. The gas-oil ratio drops slightly during the early stage of production until the critical gas saturation is reached, rises rapidly from then on and eventually passes through a sharp maximum just before the economic limit of production is reached. For the radial example presented in this paper, the average oil saturation of the reservoir at a time corresponding to the limit of economic production was 56.5 per cent and the ultimate recovery was 6.86 per cent. The difference between change in saturation and ultimate recovery is caused by shrinkage of the oil-phase.

The solution time with the 701 Computer is sufficiently short to permit an economically feasible investigation of the effects of variation of the many parameters which describe an oil reservoir. In particular, the ultimate recovery for various systems can be determined as a function of rock and fluid properties, of well spacing, and of production rate. ★★★

[1] Muskat, Morris, and Meres, M. W.: "The Flow of Heterogeneous Fluids Through Porous Media," Physics (1936), 7, 346.

Manuscript received in the Petroleum Branch office Aug. 6, 1953. Paper presented at Petroleum Branch Fall Meeting in Dallas, Oct. 19-21, 1953.

The full text of this paper will appear in *Petroleum Transactions* Volume 201 and is available in reprint form free-of-charge from the Petroleum Branch offices.

Short Length... Long Service

GUIBERSON AF PACKER

for acidizing, flooding, fracturing and other below packer pressure operations

The solid head packer you've been wanting a long time and at a price you'll be glad to pay. The AF is short, compact, strong and reliable in operation. Positive seal of pressure below the packer at any depth. Design features include friction pads, automatic latch and dove-tail slips and head. Special rubber has built-in ability to return to original shape. It will not vulcanize to casing wall and is acid, oil and gas resistant. Best of all, here is a packer you can handle—in the well or out! Over-all length of 5½" or 7" size is less than four feet!

See this packer at your favorite supply store.

THE

GUIBERSON

CORPORATION

ESTABLISHED 1919 • DALLAS, TEXAS, U. S. A.

Sold by Leading Oil Field Supply Stores Everywhere

STUDY of UNDERSATURATION during REPRESSURING and SUPERSATURATION during FLOW of OIL to WELLS

RALPH V. HIGGINS
MEMBER AIME

BUREAU OF MINES
SAN FRANCISCO, CALIF.

T. P. 3891

ABSTRACT

This paper concerns the magnitude of the amount of supersaturation that occurs in an underground reservoir during the flow of oil and gas to wells and to the amount of undersaturation that occurs during repressuring of an oil reservoir where some effective permeability to gas exists.

The study is based on earlier laboratory findings of other investigators on the rate of diffusion of gas in oil as a function of the depth of oil. Utilizing these relationships and the principles of reservoir mechanics, a quantitative estimate of undersaturation and supersaturation was calculated. The results showed that the diffusion of the gas is rapid enough that for all practical purposes no supersaturation exists during the flow of oil to wells or undersaturation during repressuring in reservoir sands having some effective permeability to gas.

The reason diffusion of the gas virtually keeps the oil saturated is the long time required in radial flow for oil to reach the well and the slow rate at which pressure in reservoirs is increased during repressuring.

INTRODUCTION

Knowledge of the phase relationships during flow of gas and oil in an underground reservoir is essential to operating the reservoir in the most efficient manner. In material-balance calculations and in fluid-flow studies, the oil is assumed to contain all the gas that it will dissolve at given temperature and pressure. Pressure-volume-temperature relationships are normally obtained in the laboratory using "bottom-hole" or combined samples of the reservoir fluids. In such laboratory determinations equilibrium is obtained between the oil and gas in the pressure cells by mechanical agitation. During the flow of oil and gas in reservoirs, however, no comparable agitation occurs to mix thoroughly these fluids to aid in effecting equilibrium between the two phases.

During repressuring of a partly depleted underground reservoir, the gas is usually injected into the reservoir faster than the oil can absorb it; consequently, the oil is undersaturated. On the other hand, as the oil flows through the reservoir to the wells during producing operations the pressure decreases faster than the gas in solution can diffuse through the oil to the gas phase. The oil therefore is supersaturated with gas. Where the oil is undersaturated, gas diffuses away from the gas-oil interface, and where it is supersaturated the gas diffuses toward the interface. In either case the gas moves from a higher to a lower saturation.

This report contains the results of a study of the factors influencing the degree of nonequilibrium of the phase relations of oil and gas in porous mediums during the flow of oil through reservoirs to wells and also during the injection of gas into partially depleted sands. Data from an underground reservoir are presented and the degree of supersaturation during the flow of the oil through the reservoir to the well is approximated. Also data from another reservoir are used and the degree of undersaturation during the repressuring operation is calculated.

In addition, the flow rates of oil in laboratory experiments and in underground reservoirs are compared, as data from the laboratory are often used to interpret events in the reservoir, and the rates of flow influence appreciably the degree of nonequilibrium.

Much of the contents of this report was prepared in 1943; but, because of other activities during and since the war, the manuscript was left untouched until 1952, when it was decided to include an estimate of the amount of undersaturation during repressuring as well as supersaturation during flow.

[1]References given at end of paper.

Manuscript received in the Petroleum Branch office Aug. 17, 1953. Paper presented at the Pacific Petroleum Chapter Fall Meeting in Los Angeles, Calif., Oct. 1-2, 1953.

UNDERSATURATION DURING REPRESSURING

After a reservoir has been partly depleted of its oil by expansion of the dissolved gas the oil in the upper part of the zone may drain downward and fill the space vacated by the oil that flowed from the bottom of the zone to the wells. If the oil moves downward readily, gravity drainage is very active. Lacey[1] in 1933 published calculations of the rate of gas diffusion for a virgin reservoir or where the oil had drained thoroughly enough to completely fill (no free gas) all the pores of the sand below the gas cap. In one of his examples, in which the depth of the liquid-filled sand was 10 ft, the time " required (after pressure above the oil body has been increased) for dissolving half the amount of gas which would eventually dissolve due to the increase in pressure" was 33 years. This is a rather long time.

Interpretations of the experiments of Muskat, Wyckoff, Botset, and Meres[2] indicate that during the expulsion of oil by dissolved gas, part of the liberated gas accumulates in the pores as the oil is forced to the well. The accumulated gas in the pores allows most of the gas that is liberated later, with reduction in pressure, to move readily through the gas phase without forcing appreciable oil to the wells. As a consequence, much oil is left behind in the pores, and the effective permeability to the gas through the pores at this stage is very high and to oil very low.

Repressuring Operations

During repressuring operations the effective permeability to gas allows the gas to move freely through the pores, unless gravity has been so effective as to displace the gas associated with the oil from the pores. If such efficient drainage to the bottom of the formation should occur, the oil at the bottom would be able to move equally as rapidly to wells as it moved to the bottom of the formation, owing to gravity or augmented by the piston-like action of the gas injected for repressuring. The mechanism would be somewhat similar to oil and gas in a tank without any porous mediums. This would result in an unusually high recovery.

Probably the greater part of the oil remains in the pores of most reservoir sands after depletion by the expansion of the dissolved gas, as the usual recovery from field reservoirs depleted by expansion of dissolved gas is less than 25 per cent of the oil in place, whereas when gravity drainage is active the recovery is much greater. Even when gravity drainage is active it is doubtful if the upward movement of the gas and downward flow of the oil are such as to completely displace the gas with oil from the pores of the lower part of the reservoir. Accordingly, only the more common condition in which some effective permeability to gas exists throughout the reservoir before repressuring is considered in this report.

As the pressure in a reservoir is raised by gas injection, the oil not in immediate contact with the gas-oil interface becomes undersaturated because the gas does not diffuse through the oil fast enough to completely saturate the oil to the equivalent concentration of the gas in the oil at the gas-oil interface. The more the oil becomes undersaturated with gas, the more rapidly the gas diffuses, and finally a condition is reached where the degree of undersaturation remains unchanged. At this point the rate of diffusion of the gas through the liquid balances with the rate of change in saturation at the interface as the pressure increases.

Quantitative Relationship

The quantitative relationship between the quantity of gas entering an interface and diffusing through an oil as related to the depth of the oil, time interval, and diffusion constant has been presented by Pomeroy, et al.[3] These investigators measured the rate of solution of methane in gasoline and proved experimentally that the following equation is valid. It represents the relation of the rate of solution of a gas in a quiescent liquid when the liquid is 50 or more per cent saturated with the gas.

$$Q = C_s AL \left[1 - \frac{8}{\pi^2} e^{Dt \left(\frac{\pi}{2L}\right)^2} \right] \quad . \quad (1)$$

where

Q = total quantity of gas which has diffused into the liquid, cubic feet.

C_s = saturation concentration, cubic feet of gas per cubic foot of solution.

A = area at right angles to direction of flow, square feet.

L = depth of the liquid, feet.

D = diffusion constant, square feet per second.

t = time, seconds.

e = base of natural logarithms.

If Equation (1) is divided by $C_s AL$ it becomes

$$f = \frac{Q}{C_s AL} = \left[1 - \frac{8}{\pi^2} e^{Dt \left(\frac{\pi}{2L}\right)^2} \right] \quad . \quad (2)$$

where f is the saturation fraction — ratio of the quantity of gas in solution to the quantity of gas that would be in solution if the oil were completely saturated.

An examination of Equation (2) shows that the time required for the oil to become completely saturated is very long compared to the time required for a slightly undersaturated oil to become less undersaturated. It is doubtful if complete saturation is reached in the flow of oil and gas mixtures through porous mediums, but the approach to complete saturation is so close that complete saturation may be assumed by the petroleum engineer.

The required value of f necessary to cause the rate of diffusion of gas in the liquid to equal the rate at which the gas is to be absorbed, owing to the increasing pressure, is a measure of the degree of undersaturation existing during repressuring. Using the physical properties of a sample of oil from Elk Hills field, Calif., the degree of undersaturation has been calculated as follows:

The rate of change in undersaturation is obtained in convenient form by differentiating Equation (2) with respect to t:

$$df/dt = \left[\frac{8}{\pi^2} e^{-Dt \left(\frac{\pi}{2L}\right)^2} \right] D \left(\frac{\pi}{2L}\right)^2 \quad . \quad (2a)$$

or

$$df/dt = (1 - f)\ D \left(\frac{\pi}{2L}\right)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Degree of Undersaturation

By means of this equation the degree of undersaturation, $1-f$, can be approximated with respect to the diffusion of gas into oil with increasing pressure.

The term df/dt is the rate at which gas is being absorbed because of the degree of undersaturation, $1-f$. When df/dt is made equal to the rate at which gas is provided by the increasing pressure, the degree of undersaturation, $1-f$, which will maintain the gas output (owing to increased pressure) and input (owing to absorption) in balance, can be calculated.

The $\frac{df}{dt}$ for the increasing gas pressure is calculated as follows:

$$\Delta f = \frac{F\Delta p}{C_s} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

C_s = cubic feet of gas per cubic foot of solution when the oil is 100 per cent saturated at the pressure p.

F = cubic feet of gas which dissolves in a cubic foot of oil for each increase of 1 psi in pressure. F varies with the pressure but may be assumed constant through a narrow pressure range.

According to Fig. 3B of a report by Cook and Shea,[4] F is about 0.022 for Elk Hills, Calif., crude oil between the limits of 600 to 1,500 lbs/sq in. Then

$$\frac{\Delta f}{\Delta t} = \frac{0.022\Delta p}{C_s \Delta t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$\frac{df}{dt} = \frac{0.022}{C_s} \frac{dp}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Equating the member of this equation at the right with the member of Equation (3) at the right and solving for $1-f$ results in the degree of undersaturation that will keep in balance the rate of gas absorption and the rate at which gas is brought to the gas-oil interface. Thus, in the illustrated example that follows, the pressure in the formation is assumed to increase 2 lbs/24 hours; therefore, dp/dt is 2/86,400, or the rate of pressure change per second. The maximum thickness, L, of an oil film in pores of the sand was assumed to be 9.8×10^{-4} ft, which is 0.03 cm. The average thickness of the oil film is much less but use of the maximum thickness results in a conservative estimate of the degree of undersaturation.

The effect of pore size on the thickness of the oil film is discussed in detail in the section of the report entitled "Pore Shape and Flow Characteristics." The value of D, the diffusion constant, is 1.9×10^{-5} sq ft/sec and is the value determined by Hill and Lacey[5] in their experimental work. The foregoing value of D is about that measured for Ventura crude oil at 86°F and it would be considerably more at reservoir temperature. The use of the smaller value, however, results in more undersaturation and is, therefore, a conservative value to use. According to Fig. 3B in the foregoing report by Cook and Shea, C_s at 700 lbs/sq in. is about 15 cu ft/cu ft of solution. Using these values in Equations (3) and (7)

$$\frac{0.022}{15} \times \frac{2}{86{,}400} = (1-f)\ 1.9 \times 10^{-5} \left(\frac{3.14}{2 \times 9.8 \times 10^{-4}} \right)^2$$

Solving for the degree of undersaturation, $1-f = 6.9 \times 10^{-7}$ or the per cent undersaturation is 100 $(1-f)$ or 0.000069 or 6.9×10^{-5} per cent. Thus with the pressure increasing at the rate of 2 lbs/day, undersaturation is practically nil. This results from the thin oil film and the appreciable time.

Discussion of Equation

The foregoing method of approximating the undersaturation has been based on an equation that has been tested experimentally. However, in using this equation the analogy is not perfect, as Equation (1) is based on a fixed saturation at the gas-oil interface instead of a slowly changing one. In an unpublished manuscript on the subject prepared in 1942, the writer treated supersaturation quantitatively and undersaturation qualitatively. R. H. Olds, one of the reviewers of the paper, suggested an equation and included its derivation for treating supersaturation so as to accurately account for the slowly changing saturation at the oil-gas interface. By a change in sign in the fore part of Olds' derivation, because of the inward diffusion of gas during undersaturation instead of its outward diffusion during supersaturation, and by proceeding in an analogous manner with the derivation, the same equation is obtained for undersaturation as for supersaturation. The derivations for both undersaturation and supersaturation are presented later in the report.

The degree of undersaturation when the slow change in the gas saturation at the oil-gas interface is included is

$$\text{per cent undersaturation} = \frac{100\,L^2}{3Dp} \frac{dp}{dt} = 5.6 \times 10^{-5}$$

Thus both methods of estimating the degree of undersaturation result in about the same negligible amount of undersaturation.

SUPERSATURATION DURING FLOW

As oil moves through reservoir sands to wells, with decreasing pressure, part of the gas in the oil phase exceeds that required to saturate the oil at the decreased pressure. The excess gas diffuses to the oil-gas interface at a rate depending in part on the rate at which the pressure decreases. Because the gas does not diffuse rapidly enough from the oil to maintain the same gas saturation in the oil as exists at the gas-oil interface, some supersaturation exists. Marked difference exists between this supersaturation and a supercooled liquid such as water, commonly mentioned in school textbooks on physics and chemistry. The property of the latter system is such that a small, sharp surface can cause instantaneous formation of ice and raising of the temperature to that of freezing ice. In the supersaturated oil considered in this report no comparable instantaneous lowering of the gas concentration to that at the gas-oil interface occurs. The gas diffuses according to the unsteady-state equations for the diffusion of dissolved gases through liquids. The prefix super is used because the quantity of gas in solution exceeds that at the gas-oil interface.

In the radial flow of oil to wells, the rate of pressure change with time depends on the distance from the well, and this rate of change can be approximated by using the radial flow equation for oil and differentiating with respect to t. Thus:

$$\frac{p - p_w}{p_e - p_w} = \frac{ln \frac{r}{r_w}}{ln \frac{r_e}{r_w}} \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where

p = pressure at the radius r from the axis of the well, pounds per square inch absolute.

p_w = the back pressure at wall of well, pounds per square inch absolute.

p_e = pressure at the outer boundary, r_e, pounds per square inch absolute.

r_w = radius of well, feet.

r_e = radius of external pressure boundary, feet.

r = any radius, feet.

ln = natural logarithm.

These equations are for an incompressible liquid, and therefore the results are not as accurate as if those for two phase flow had been used.
The differential equation is

$$\frac{dp}{dt} = \frac{p_e - p_w}{ln \frac{r_e}{r_w}} \frac{1}{r} \frac{dr}{dt} \quad . \quad . \quad . \quad . \quad (9)$$

The term dr/dt is the velocity, and for radial flow of oil through porous mediums

$$\frac{dr}{dt} = \frac{Q}{2\pi r\ h\ m\ w} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where

Q = flow rate, cubic feet per second.

h = sand thickness, feet.

m = porosity of the sand, fraction.

w = pore space through which the advancing oil front moves, fraction.

By means of Equation (10) by m and w, the velocity is corrected for the presence of the sand, interstitial water, and immobile oil.

Substituting the value of dr/dt from Equation (10) for dr/dt in Equation (9) results in

$$\frac{dp}{dt} = \frac{p_e - p_w}{ln \frac{r_e}{r_w}} \frac{Q}{2\pi r^2\ h\ m\ w} \quad . \quad . \quad . \quad (11)$$

the relation for the rate of change of pressure with time along a radial flow line.

When an oil is supersaturated with gas, the gas diffuses from the oil; consequently, df/dt is negative instead of positive because the saturation fraction is decreasing. When the change in sign for df/dt is made in Equation (3), it becomes

$$\frac{df}{dt} = (f - 1)\ D\left(\frac{\pi}{2L}\right)^2 \quad . \quad . \quad . \quad (11a)$$

Equation (11a), relating the rate of change of saturation with time to the degree of supersaturation, the diffusion constant, and the depth from which the oil diffuses; Equation (11), representing the rate of pressure change; and Equation (6), relating the rate of change of saturation with pressure, were used to estimate the degree of supersaturation along a radial flow line in the reservoir of the Kettleman Hills field.

The constants in Equation (6) are for the crude oil in Elk Hills reservoir. When the constants for Kettleman Hills crude oil between the limits of 600 to 1,000 psia are substituted Equation (7) becomes

$$\frac{df}{dt} = \frac{0.043}{C_{s_r}} \frac{dp}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where C_{s_r} = cubic feet of gas per cubic foot of solution

when the oil is 100 per cent saturated at a pressure, p, a radial distance, r, from the well axis. Combining of (11a), (11), and (12) then gives the degree of supersaturation along a radial flow line:

$$f - 1 = \frac{0.043}{C_{s_r}} \frac{Q}{2\pi r^2\ h\ m\ w} \frac{(2L)^2}{D\pi^2} \frac{p_e - p_w}{ln \frac{r_e}{r_w}} . \quad (13)$$

In the radial flow of an oil through reservoir sands to a well, the maximum pressure drop per unit of time or per unit distance exists at the well wall; consequently, the supersaturation that exists should be a maximum at the well wall and appreciably less a few feet away. By means of Equation (13), the amount of supersaturation at the well wall of a Kettleman Hills well has been approximated. For this approximation the following values of some of the terms in Equation (13) were assumed to be reasonable from the meager data that are available.

C_{s_r} = 21 cu ft of gas/cu ft of oil at r_w, where p = 600 psi

$Q = 1.3 \times 10^{-2}$ cu ft/sec, which 200 B/D

r = 0.25 ft for this particular problem

h = 312 ft

m = 0.15

w = 0.20

$L = 9.8 \times 10^{-4}$ ft, which is 0.03 cm (The pore size is probably much less)

$D = 1.9 \times 10^{-5}$ ft²/sec, which is 2×10^{-5} cm²/sec

p_e = 1,000 psia

p_w = 600 psia

r_e = 200 ft

r_w = 0.25 ft

When the foregoing values are substituted in Equation (13) the result is 0.0087 or 0.87 per cent supersaturation. Hence the supersaturation at the well wall where the greatest amount exists is small and is much less a short distance away from the well wall, therefore supersaturation may be neglected in most engineering studies.

Substituting the foregoing values and using Equation (11) and Olds' equation, the per cent supersaturation is 0.60, which is somewhat less than that obtained by the use of Equation (13).

Laboratory experiments also indicate that the degree of supersaturation at the usual rates of oil production in field practice is very small. Stewart et al[6] have shown that the degree of supersaturation decreases markedly with the decreasing production rate of oil and gas from cores and "extrapolation of the laboratory data indicates very little supersaturation will exist under most field conditions."

Derivation of Equation for Changing Gas Saturation

The derivation of the Olds' equation, which accounts for the changing gas saturation at the gas-oil interface, is as follows:

Consider a thin layer of oil which has been saturated with a single component gas and is now in dynamic equilibrium with a slowly and uniformly decreasing gas pressure at the gas-oil interface. The pressure has been decreased sufficiently to eliminate any transient effects associated with initial lowering of the gas pressure.

The differential equation relating the variables as given in texts is

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial l^2}, \quad \ldots \quad (a)$$

where

C = concentration of gas in solution.

t = time.

D = diffusion constant, and

l = depth of oil measured from gas-oil interface.

A linear relation between the gas pressure and the saturation pressure (Henry's law) is assumed, then

$$C = b\ p, \quad \ldots \quad (b)$$

where p = pressure and b = solubility constant. Then at the oil-liquid interface,

$$\frac{dC_o}{dt} = b \frac{dp}{dt}, \quad \ldots \quad (c)$$

where C_o = concentration of gas in the oil phase at the gas-oil interface.

After sufficient time has elapsed to permit decay of transient effects associated with the initial lowering of pressure, a steady decline in pressure will produce a corresponding steady decline in concentration throughout the liquid. Then it may be assumed that the time rate of change of concentration at any depth in the liquid is the same as that at the gas-oil interface. Hence,

$$\frac{\partial^2 C}{\partial l^2} = \frac{b}{D} \frac{dp}{dt} \quad \ldots \quad (d)$$

The integration Equation (d) with respect to l and the insertion of the boundary conditions, $C = C_o$ when $l = 0$, and $\partial C/\partial l = 0$ when $l = L$, yields

$$C = C_o - \frac{b\ L}{D} \frac{dp}{dt} l + \frac{b}{2\ D} \frac{dp}{dt} l^2 \quad \ldots \quad (e)$$

This equation gives the gas concentration for any depth of oil and an examination of the equation will show that the gas concentration increases as the distance from the gas-oil interface increases.

The degree of supersaturation is calculated as follows:

$$\text{Per cent supersaturation} = 100 \frac{Q - Q_o}{Q_o}, \quad \ldots \quad (f)$$

where Q_o = the quantity of gas in solution corresponding to a uniform concentration C_o throughout the liquid. The quantity of gas in solution in the liquid is

$$Q = \int_0^L AC\ dl, \quad \ldots \quad (g)$$

where A = area normal to flow by diffusion and l = depth of oil measured from the gas-liquid interface. Then per cent supersaturation

$$= 100 \frac{\int_0^L A\ C\ dl - \int_0^L A\ C_o\ dl}{\int_0^L A\ C_o\ dl}, \quad \ldots \quad (h)$$

$$= -100 \frac{L^2}{3DP} \frac{dp}{dt}, \quad \ldots \quad (i)$$

which is Olds' equation for supersaturation.

Equation (i) is independent of the concentration and solubility of the gas in the liquid as a consequence of the assumption of Henry's law in the derivation

If Equation (e) is applied to the data pertaining to Fig. 8 of the article by Gurney and Lurie,[7] the same results as are shown in their figure will be obtained at any time except for the initial 8-minute period. To obtain the same results, temperature is substituted for concentration and thermal diffusivity for the diffusion constant in Equation (e).

Thus the validity and method of derivation of Equation (e) are proven by data which have been obtained by the use of the Fourier series. Incidentally, the curves of Gurney and Lurie also can be applied to determine the variation of gas saturation with depth.

PORE SHAPES AND FLOW CHARACTERISTICS

The equations in the foregoing section are based on linear diffusion from a mass of oil having a uniform cross sectional area A and length L and a volume represented by AL. Because of the shape of the pores and the mechanics of flow of gas and oil in porous mediums, simple linear diffusion seldom takes place. It will be shown that the value of L used in the report results in the gas diffusing at a slower rate in a pore than actually occurs. As a result, the degree of super or undersaturation calculated in the report would be less if an attempt were made to choose a factor to alter L to a length which would approach accurately the equivalent of what is happening in a pore.

The cross sectional area of the pores resulting from the cubic and rhombohedral packing of uniform spheres are similar to two triangles placed base to base. According to the results of experiments by Wyckoff and Botset,[8] probably the first bubbles accumulate at the base of the triangles in the flow stream, because the permeability of porous mediums decreases rapidly at first without the efflux of appreciable free gas from the sand face. During this initial period the permeability is decreased more than would be expected by the volume increase of gas in the pores of the sand. Therefore the bubbles of gas must occupy positions which offer considerable resistance to the flow of the oil phase.

Bubbles that accumulate in the flow stream require much of the oil phase to pass around the bubble, decreasing the over-all time required for gas to diffuse from the oil phase to the bubble. Also, gas from a bubble at the base of the triangles would have only to diffuse half the distance to the extremities of the pore than if it were in the apex of one triangle. Thus the factors indicate that, where there is some effective permeability to gas, the use of the distance between the apexes of the triangles is conservative.

Length L used in the illustrative examples is the distance between the apexes of triangles formed by the cubic packing of uniform spheres having diameters (0.03 cm) equivalent to the openings in a No. 48-mesh screen (Tyler). The mean length L should be much less for the Kettleman Hills formation containing sands of different grain sizes mixed and cemented as to give an average permeability of the order of 250 md. The cubic packing of uniform spheres 0.03 cm in diameter result in porous mediums having a permeability greater than 24,000 md. Therefore, the choice of $L = 0.03$ cm for the illustrative example pertaining to Kettleman Hills is thought to be conservative, in that a shorter length would result in still less supersaturation.

The use of $L = 0.03$ cm in the calculations results in extremely low value for undersaturation during repressuring and in very low value for supersaturation a short distance from the well wall. If $L = 1$ in. and where the pressure in the reservoir is changing at the rate of 2 psi/24 hours, the under or supersaturation would be only 0.5 per cent. Accordingly, the use of $L = 0.03$ cm is not critical.

In some reservoirs containing undersaturated oils there may be a transient period before gas accumulates immediately following reduction in pressure below that of the bubble point.[9] In the radial flow of oil to wells, however, the time element for any unstable condition to come to equilibrium is very long.

TIME ELEMENT IN LINEAR AND RADIAL FLOW

Many experiments are conveniently performed in the laboratory to study the flow behavior of oil in field reservoirs. As time is important in the diffusion of gas through oil, the example calculations, which follow, are presented to show that in the radial flow of oil through underground reservoirs to wells much more time is required than in linear flow of oil through laboratory cores.

The time required for a globule of oil to move through the formation from a point 100 ft from the well axis to the well was calculated by integrating the Differential Equation (10). The integrated equation is

$$t = \frac{\pi hmw}{Q}(r^2 - r_w^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Substitute the following in Equation (14):

$r = 100$ ft, the distance from the well axis

$h = 312$ ft, the thickness of the formation

$m = 0.15$, the porosity

$w = 0.20$, the fraction of the pore space occupied by moving oil front

$Q = 1.3 \times 10^{-3}$ cu ft/sec (200 B/D), the flow rate of oil

The result is 22.6×10^6 seconds or 262 days, the time for a globule of oil to travel from a point 100 ft from the well axis to the well wall.

In a linear core having the same permeability, the same pressure drop from entrance to exit, and the same velocity at the outlet face as the condition in the foregoing field example, the time required for a particle of oil to travel the length of the core is much less than for the corresponding length in radial flow.

The velocity in the reservoir at any place in radial flow of oil is

$$v_r = \frac{K}{u} \frac{p_w - p_e}{r \ln \frac{r_e}{r_w}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

where v_r is the velocity at any radius r, K is the permeability, and u is the viscosity of the oil.

The corresponding equation for velocity in linear flow is

$$v = \frac{K}{u} \frac{p_i - p_o}{n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

where v is the velocity of the oil in the channel, p_i is the inlet pressure, p_o is the outlet pressure, and n is the length of the channel.

The velocity of the oil at the sand face in the well and at the outlet of the core are identical. The radius r_w of the well is 0.25 ft and $p_i - p_o = p_e - p_w$. Then the division of Equation (15) by Equation (16) and substitution of 0.25 for r_w, results in

$$\ln \frac{r_e}{0.25} = \frac{n}{0.25} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

Table 1, based on Equation (17), shows the comparative distances for linear and radial flow systems for equal pressure drops and the same velocities at the outlet face. The data show the much greater distance required for radial as compared to linear flow. For example, when r_e is 100 ft in the radial system, the length of the linear core is 1.5 ft.

TABLE 1 — RELATION BETWEEN DISTANCES IN LINEAR AND RADIAL FLOW.

Length of linear channel, n, feet	Distance from well axis to outer boundary in radial flow, r_e, feet
0.5	1.8
1.25	37
1.50	100
1.75	274
2.00	745
2.50	5,500

In the example given in the first part of this section a radial distance of 100 ft was used and the time required for an oil globule to reach the wall was 262 days. In that example in which the time interval was 262 days, the velocity dr/dt at the well wall, r = 0.25, is found to be 8.9×10^{-4} ft/sec.

In the linear flow of a homogeneous liquid, the velocity at all points in the core is the same as at the outlet; therefore the time required for an oil particle, having the same properties as the oil in the radial flow example, to travel from the inlet to the outlet of a linear channel 1.5 ft long is $1.5/(8.9 \times 10^{-4})$ or 1,690 seconds or 28 minutes. This is appreciably different from the 262 days in the radial flow example and is a factor to consider in making any laboratory experiments to determine the amount of supersaturation of gas in oil contained in reservoirs about wells.

CONCLUSION

This study has been made to estimate the degree of non equilibrium between oil and gas in an underground reservoir during the flow of oil and gas to a well and during repressuring operations. According to the experiments of Wyckoff and Botset, when the pressure on the oil is reduced below the bubble point in an underground reservoir by the movement of oil to wells, gas accumulates in the pores of the formation. During repressuring operations, the oil at the gas-oil interface in the pores instantaneously becomes com-

pletely saturated at the new pressure resulting from the gas injection. The gas diffuses from the interfaces into the oil.

Equations relating the depth of oil, the concentration of the gas in solution, and the time for the gas to diffuse were developed and applied. The results show that the degree of undersaturation of the oil with gas would be negligible in systems of the type considered. This conclusion arises from the small quantity of oil through which gas diffuses in pores where some effective permeability to gas exists and the long time required to increase the pressure in a large reservoir by gas injection.

The corresponding situation exists in a reservoir during the flow of oil through reservoir sands to wells, even to the long time available for the gas to diffuse. An example is presented which shows that 262 days would be required for an oil particle to move 100 ft radially through an oil reservoir to a well when oil is flowing into a well at a rate comparable to that in many fields. Consequently, gas has appreciable time in which to diffuse.

In laboratory flow tests the oil seems to move very slowly through the cores, but when compared to flow rates in underground reservoirs the movement is fast. For example, it was found that a laboratory core 1.5 ft long offered the same resistance to linear flow as that presented to radial flow through 100 ft of a selected underground reservoir. With the same velocity of flow at the outlet face of the core as at the well face, the calculated time required for the oil to move through the core was 28 minutes, compared to 262 days for the oil to travel the radial distance of 100 ft in the selected underground reservoir.

This time difference in the laboratory and field is a factor to consider in making any laboratory experiments to determine the degree of nonequilibrium of gas in oil contained in reservoirs about wells as the longer the time, the less the supersaturation during flow and the less the undersaturation during repressuring.

The general conclusion may be made that, in pores of those underground reservoirs which have some effective permeability to gas, virtually complete equilibrium between oil and gas can be assumed for most reservoir engineering investigations using pressure, volume, and temperature data, because the slow rate of flow in underground reservoirs and the short distance through which gas has to diffuse allows enough time for the gas virtually to saturate the oil completely.

In other words, for the purpose of this report, it is assumed that the more common condition in partly depleted, solution-gas-drive reservoirs will be one of an existing effective permeability to gas (also in sections of other reservoirs where this condition exists) and that the gas will be distributed in the oil zone such that the depth of the oil through which gas diffuses during conditions of phase nonequilibrium will not exceed the average pore diameter. For the examples treated in the report, the average pore diameter is considered to be equal or less than 0.03 cm (the opening in a 48-mesh screen) and this value is used as the depth of diffusion L. In other systems where L may appreciably exceed this value, the results presented in this report would be altered accordingly. The equations presented can be used to calculate the magnitude of the alterations. In one such calculation L was chosen to be 1 in. and the rate of pressure change in the reservoir 2 psi per 24 hours. The super- or undersaturation was of the order of 0.5 per cent, therefore, the use of $L = 0.03$ cm is not critical, except at or near the well wall.

If appreciable super- or undersaturation is found to exist in reservoirs that fulfill the conditions in this report, then some other factor than diffusion and Wyckoff and Botset's principles of fluid flow must be operative.

ACKNOWLEDGMENTS

The investigation was conducted under the supervision of R. A. Cattell, chief, Petroleum and Natural Gas Branch, Bureau of Mines, Washington, D. C., and G. B. Shea, chief, Fuels Technology Division, Region III, Bureau of Mines, San Francisco, Calif.

Thanks are extended to the following: V. J. Berry, Jr., Stanolind Oil & Gas Co; Michael J. Rzasa, Cities Service Research and Development; and Harvey T. Kennedy, R. L. Whiting, Paul B. Crawford, A&M College of Texas; E. M. Tignor, John F. Noonan, James L. Moore, C. Kenneth Eilerts, Alton B. Cook, R. V. Smith, G. L. Gates, F. G. Miller, and especially C. Q. Cupps, Bureau of Mines, for their helpful suggestions and criticisms in preparing the report.

REFERENCES

1. Lacey, William N.: "Practical Benefits of Pressure Maintenance in Petroleum Production," API Production *Bull.* (1933), **210**, 18.
2. Muskat, M., Wyckoff, R. D., Botset, H. G., and Meres, M. W.: "Flow of Gas-Liquid Mixtures Through Sands," *Trans.* AIME (1937), **123**, 247.
3. Pomeroy, Richard D., Lacey, William N., Scudder, Nathan F., and Stapp, Frederick P.: "Rate of Solution of Methane in Quiescent Liquid Hydrocarbons," *Ind. Eng. Chem.* (September, 1933), 1015.
4. Cook, Alton B., and Shea, G. B.: "Special Studies of Reservoir Oils in Naval Petroleum Reserve No. 1, Elk Hills field, California." Bureau of Mines Report of Investigations 4054 (1947).
5. Hill, E. S., and Lacey, W. N.: "Rate of Solution of Methane in Quiescent Liquid Hydrocarbons," *Ind. Eng. Chem.* (December, 1934), **2**, 1325.
6. Stewart, C. R., Craig, F. F., Jr., and Morse, R. A.: "Determination of Limestone Performance Characteristics by Model Flow Tests," *Trans.* AIME (1953), **198**, 98.
7. Gurney, H. P., and Lurie, J.: "Charts for Estimating Temperature Distributions in Heating or Cooling Solid Shapes," *Ind. Eng. Chem.* (November, 1923), 1172.
8. Wyckoff, R. D., and Botset, H. G.: "Flow Through Unconsolidated Sands," *Physics* (1936), 325-345.
9. Kennedy, H. T., and Olson, C. R.: "Bubble Formation in Supersaturated Hydrocarbon Mixtures," *Trans.* AIME (1952), **195**, 271-278. ★★★

SUREST WAY TO FIND MOST PRODUCTIVE ZONE

HALLIBURTON'S HYDRO-SPRING TEST

It costs so little and saves so much that many operators run a Hydro-Spring Test even in proven areas. There's no surer way to find your most productive zone.

Giving due credit to surface geology, core records, and electric logs, their findings are confirmed only when the Hydro-Spring Tester and the Bourdon Tube Pressure Recording Device come up with the final answer.

With so much at stake you want the best drill stem test—and Halliburton has it in Hydro-Spring.

here's why:

Perfect performance, with rarely a mis-run, saves you time, trouble, money. Hydro-Spring opens easily by weight of drill pipe only and gives positive surface indication. Smoothest test you ever ran.

Reaches bottom easier and can be run in faster, even in tight holes. Equalizing By-Pass reduces possibility of damaging formation, prevents fluid loss to formation.

Precise pressure recording, most accurate available, provided by Bourdon Tube on special copper plate that is laboratory checked. Included with Standard Recording at no extra charge.

Instant Packer Release—no jarring or pulling the new Expanding Shoe Packer. Steel sole of shoe prevents rubber extruding beyond working limits, leaves little or no rubber in hole.

Support your decision with the best in drill stem testing—Halliburton's Hydro-Spring. It provides the four most important features, is first choice with the most operators, is the only testing service backed by 30 years' research and two-million-job experience. And it's more available—with 211 service centers in this country alone. Phone your local or district Halliburton office, just minutes away. Or contact Halliburton Oil Well Cementing Company, Duncan, Oklahoma.

Hydro-Spring Tester—Patent Applied For

TESTING
HALLIBURTON
SERVICE

HALLIBURTON'S BEST FOR YOUR DRILL STEM TEST

GAS HYDRATES of HYDROGEN SULFIDE-METHANE MIXTURES

LESLIE J. NOAKER
DONALD L. KATZ
MEMBER AIME

UNIVERSITY OF MICHIGAN
ANN ARBOR, MICH.

T. P. 3895

ABSTRACT

Experimental data are presented for hydrate formation conditions for mixtures of hydrogen sulfide and methane. Vapor-solid equilibrium constants for hydrogen sulfide are also presented. Equilibrium constants, defined here as the ratio of the mole fraction of hydrogen sulfide in the vapor phase (dry basis) to the mole fraction of hydrogen sulfide in the solid phase (dry basis), were calculated using the vapor-solid equilibrium constants for methane presented in an earlier paper. The conditions at which a natural gas will form gas hydrates with water may be computed from its composition, when hydrogen sulfide is present in addition to carbon dioxide and the paraffin hydrocarbons.

INTRODUCTION

Many gases are known to form solid hydrates in the presence of liquid water at temperatures above 32°F. This hydrate formation is of importance to the natural gas industry inasmuch as most of the constituents found in natural gases will form hydrates. The attention of the industry was called to hydrates by Hammerschmidt[10] in 1934. A number of papers have been written giving the temperatures and pressures at which these hydrates will form[2,4,5,6,7,8,10,13,14,15,19] and a bibliography on the subject has been compiled[12]. Deaton and Frost[4,5,6,7,8] report work for various pure gases and for some natural gases. Katz and co-workers[2,4,13,14,15,19] have reported data for various gases at high pressure. They developed a method of predicting conditions for hydrate formation from equilibrium constants[2,19] and from gas gravity.[11] The effects of anti-freeze agents on the formation of hydrogen sulfide hydrate were reported by Bond and Nelson.[2] The hydrogen sulfide-water system, including hydrate, has been the subject of recent investigation by Sage and co-workers.[17]

Mixtures of hydrates behave as solid solutions and an equilibrium exists between the vapor phase and the solid phase that appears to be comparable to the equilibrium between vapor and liquid phases.[2,19] By means of the vapor-solid equilibrium constants which have been published for methane, ethane, propane, isobutane,[2] and carbon dioxide[16] it is possible to determine the temperature and pressure at which hydrates will form for a specific gas mixture when water is present.

Hydrogen sulfide which is frequently found in natural gases has a very strong tendency to form hydrate and must enter the solid solution when present in a natural gas forming a hydrate. To determine the effect of hydrogen sulfide when computing the conditions for gas hydrate formation, it is necessary to have the equilibrium constant giving the ratio of the concentration of hydrogen sulfide in the gas phase to the concentration in the solid phase. This paper presents data on hydrate formation for mixtures of hydrogen sulfide and methane and presents the equilibrium constants which were calculated from these data.

EXPERIMENTAL PROCEDURE

The apparatus used to determine the conditions of hydrate formation for the methane-hydrogen sulfide system was similar to that employed by previous investigators.[2,18,19] A charge gas cylinder was used to supply the hydrogen sulfide-methane mixtures, called the charge gas, and to supply the pressure up to 1,000 psia. This

[1]References given at end of paper.
Manuscript received in the Petroleum Branch office on Mar. 3, 1954.

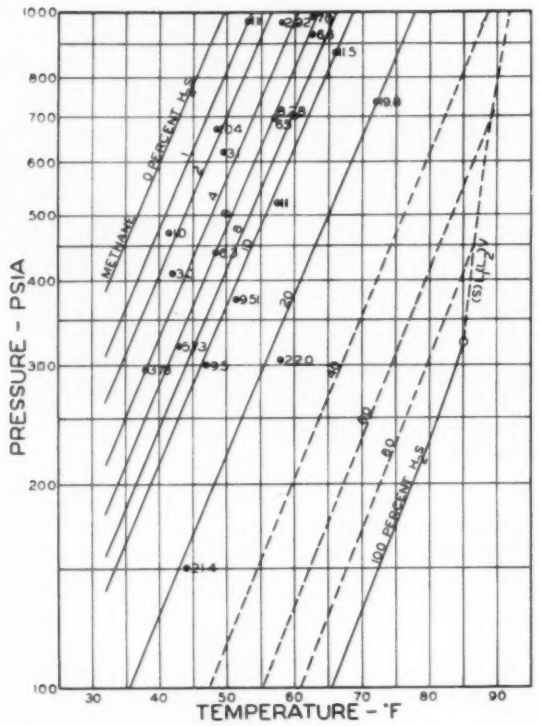


FIG. 1 — HYDRATE FORMATION CONDITIONS FOR HYDROGEN SULFIDE-METHANE MIXTURES.

cylinder was filled by introducing hydrogen sulfide gas to some pressure below the vapor pressure, and then introducing methane to a total pressure of approximately 1,200 psia. The cylinder was allowed to stand 24 hours or more to allow complete mixing by diffusion. This charge gas was analyzed to determine its composition by the Tutwiler method.[1] It involves a direct titration with standard iodine solution of a fixed volume of gas mixture, then calculating the hydrogen sulfide content from the amount of iodine solution used.

The hydrate cell had glass windows and was immersed in a constant temperature water bath. The cell was continuously rocked to agitate its contents. In charging, the hydrate cell was filled with water and the charge gas was introduced into the cell without agitation, displacing the water until 10.5 cc of water remained. The pressure in the cell was then set at the desired value by introducing additional charge gas.

The bath was cooled to some 5°F below the expected hydrate formation temperature by the addition of ice. As the cell was rocked the hydrate would form with an accompanying drop in pressure as observed by a calibrated Bourdon tube gage. The temperature, measured by a thermometer in the bath, was increased by the addition of hot water until the hydrate began to melt and the pressure to increase.

The temperature was then increased more slowly until almost all of the hydrate had disappeared. The hydrate was present as flakes adhering to the wet glass walls of the cell, so it was observed easily. The bath temperature was then reduced about a degree to cause hydrate to form again. The temperature was again allowed to rise very slowly, about 1.0°F per hour, and observations made until no more hydrate was present and no noticeable change in pressure could be observed. These two conditions would occur at substantially the same temperature.

The temperature and pressure at which the hydrate disappeared are reported as the hydrate formation conditions for the composition of the gas in the vapor phase, Table 1. Again lowering the bath temperature around 0.5°F would cause hydrate to reform, so it is felt that the formation temperature is known at least within 0.5°F. Charge gas was then introduced to produce a higher pressure and the procedure was repeated. In this manner, several points were obtained with each composition of charge gas.

The composition of the vapor phase at hydrate formation conditions was obtained experimentally by direct analysis using the Tutwiler method.[1] After purging the delivery lines a sample of vapor was drawn off, dried with magnesium perchlorate, warmed to room temperature, and analyzed in the Tutwiler apparatus. The composition of the gas phase was estimated for those points in which it was not obtained experimentally. Solubility data for hydrogen sulfide[2,15] and for natural gas[9] in water are available.

The methane was supplied through the courtesy of the Phillips Petroleum Co. with reported purity of better than 99 per cent. The hydrogen sulfide was reported to be 99.9 per cent pure.

PHASE BEHAVIOR

The data for the various mixtures were plotted on Fig. 1 and cross-plotted on Fig. 2. Fig. 1 shows the pressure-temperature relations for hydrate formation in the three component system hydrogen sulfide-methane-water. The three phase equilibrium, water-rich liquid (L_1), hydrate (S), and vapor (V) for the system methane-water[14] is represented by the line labelled 0 per cent H_2S. The similar equilibrium for hydrogen sulfide-water is shown by the line labelled 100 per cent H_2S.[2,15] The intermediate lines labelled with the per cent hydrogen sulfide in the vapor (dry basis) represent the three phase equilibrium L_1 and V saturated with S, that is, the conditions at which hydrate just begins to form, for the three component system hydrogen sulfide-methane-water at the indicated vapor phase compositions.

The S,L_1,V curve for hydrogen sulfide-water terminates at 324.7 psia and 85.1°F. At this point a fourth phase,

TABLE 1 — CONDITIONS FOR HYDRATE FORMATION WITH HYDROGEN SULFIDE-METHANE-WATER MIXTURES

Temp. °F	Press. psia	Mol % H_2S in Charge Gas	Expr. Mol % H_2S in Vapor Phase	Calc. Mol % H_2S in Vapor Phase
60.0	700	11.6	8.23	7.0
52.0	375		9.51	9.0
48.5	440	7.15		6.3
57.0	695			6.5
62.5	985			7.0
43.0	320		5.73	6.5
62.5	925		6.6	7.0
42.0	410	3.11		3.0
49.5	620			3.1
58.0	965		2.92	2.95
38.0	295		3.78	3.9
41.5	470	1.09		1.0
48.5	670			1.04
53.0	970		1.11	1.06
58.0	305	22.2		22.0
72.0	735		19.8	21.0
44.0	150		21.4	22.0
47.0	300	12.5		9.5
57.5	520			11.0
66.0	870		11.5	11.5

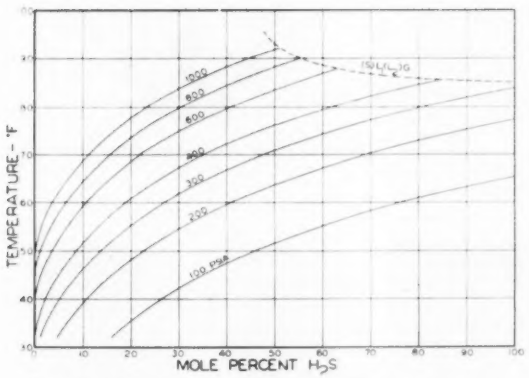


FIG. 2 — HYDRATE FORMATION CONDITIONS FOR HYDROGEN SULFIDE-METHANE MIXTURES.

the hydrogen sulfide-rich liquid (L_2) appears and the system becomes invariant. The addition of another component, methane, causes this S,L_1,L_2,V equilibrium to gain one degree of freedom and move out into the three component diagram as a single line upon which terminate the lines representing the three component L_1, V, S equilibria. On Fig. 1 this four phase line is labelled (S), L_1, (L_2), V to indicate that it represents L_1 and V saturated with S and L_2. The location of the (S), L_1, (L_2), V line was estimated using the data for the hydrogen sulfide-methane system available in the literature[18] and assuming that the presence of water has little effect on the vapor-liquid equilibrium in this system.

EQUILIBRIUM CONSTANTS

The vapor-solid equilibrium constants for hydrogen sulfide, defined as the mole fraction of hydrogen sulfide in the vapor (dry basis) divided by the mole fraction of hydrogen sulfide in the solid (dry basis), were calculated using the equilibrium constants for methane[3] and the hydrate formation conditions for gas mixtures. The hydrate formation corresponds to the dew point in vapor-liquid equilibrium. Accordingly, $\Sigma x = \Sigma y/k = 1.0$ where x and y are the mole fraction of the constituent (dry basis) in the solid phase and vapor phase respectively, and K is the vapor-solid equilibrium constant. The smoothed equilibrium constants are plotted on Fig. 3. The fact that K for a vapor containing only hydrogen sulfide would be unity was used in extrapolating the K values to 1.0. These equilibrium constants can be used along with the charts for other gases[3,19] in computing hydrate formation conditions for natural gases containing hydrogen sulfide.

ACKNOWLEDGMENT

The research was made possible by a fellowship supported by the Standard Oil Co. of California. The previous work on this subject done by J. D. Hembree was of considerable help. The pure methane supplied by the Phillips Petroleum Co. was appreciated.

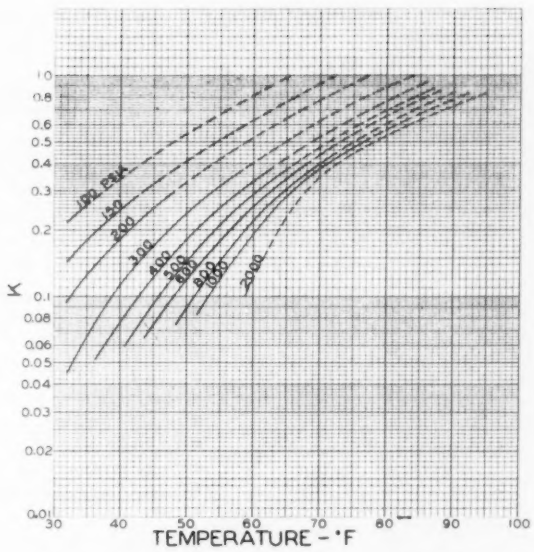
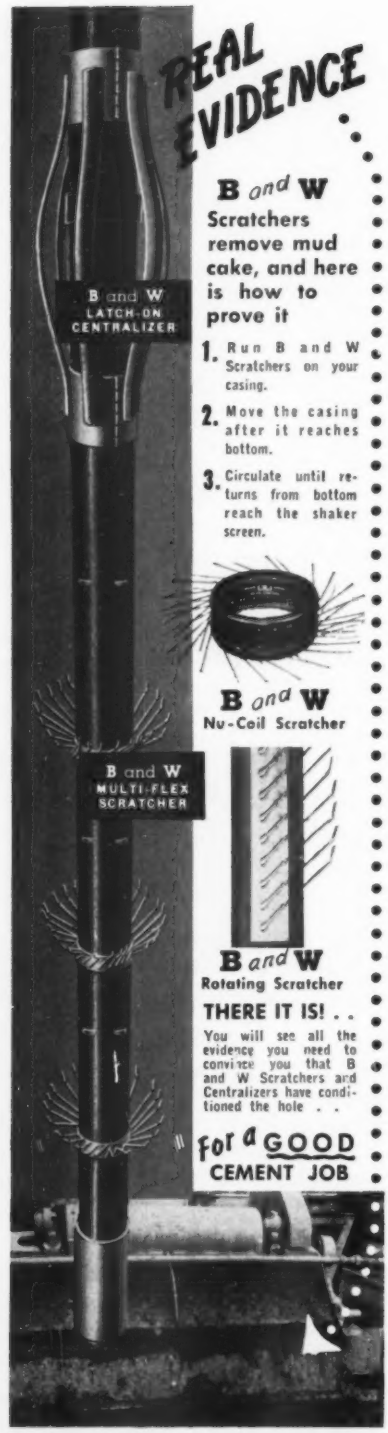


FIG. 3 — VAPOR-SOLID EQUILIBRIUM CONSTANTS FOR HYDROGEN SULFIDE.

REFERENCES

1. Altieri, V. J.: "Gas Analysis and Testing of Gaseous Materials," American Gas Association, New York, N. Y. (1945).
2. Bond, D. C., and Nelson, B. R.: AIME Pub. No. 2450 (1948).
3. Carson, D. B., and Katz, D. L.: "Natural Gas Hydrates," *Trans.* AIME (1942), **146**, 150.
4. Chinworth, H. E., and Katz, D. L., *Refr. Eng.*, (1947), 359-62, **54**.
5. Deaton, W. M., and Frost, E. M., Am. Gas Assoc., Nat. Gas. Dept. *Proc.* (1937), 23-31.
6. Deaton, W. M., and Frost, E. M.: Ibid. (1938), 112-9.
7. Deaton, W. M., and Frost, E. M.: Ibid. (1940), 122-8.
8. Deaton, W. M., and Frost, E. M.: *Oil and Gas Jour.* (1946), **45**, No. 12, 170-8.
9. Dodson, C. R., and Standing, M. B.: *Drilling and Production Practice*, API (1944), 173.
10. Hammerschmidt, E. G.: *Ind. Eng. Chem.* (1934), **26**, 851.
11. Katz, D. L.: *Trans.* AIME (1945), **160**, 140.
12. Katz, D. L., and Rzasa, M. J.: "Physical Behavior of Hydrocarbons Under Pressure," J. W. Edwards, Inc. (1946), Ann Arbor, Mich.
13. Katz, D. L., Kobayashi, R., Withrow, H. J., Williams, G. B.: Proc. Nat. Gasoline Assn. of America (1951), 27-31.
14. Kobayashi, R., and Katz, D. L.: *Trans.* AIME (1949), **186**, 66.
15. Reamer, H. H., Sage, B. H., and Lacey, W. N.: *Ind. Eng. Chem.* (1951), **43**, 976-81.
16. Roberts, O. L., Brownscombe, E. R., and Howe, L. S.: *Oil and Gas Jour.* (1940), **39**, No. 30, 37.
17. Selleck, F. T., Carmichael, L. T., and Sage, B. H.: *Ind. Eng. Chem.* (1952), **44**, 2219-26.
18. Unruh, C. H., and Katz, D. L.: *Trans.* AIME (1949), **186**, 83.
19. Wilcox, W. I., Carson, D. B., and Katz, D. L.: *Ind. Eng. Chem.* (1941), **33**, 662-5.
20. Wright, R. H., and Maass, O.: *Can. J. Res.* (1932), **6**.

★★★


REAL EVIDENCE
B and W LATCH-ON CENTRALIZER
B and W Scratchers remove mud cake, and here is how to prove it
1. Run B and W Scratchers on your casing.
2. Move the casing after it reaches bottom.
3. Circulate until returns from bottom reach the shaker screen.
B and W Nu-Coil Scratcher
B and W MULTI-FLEX SCRATCHER
B and W Rotating Scratcher
THERE IT IS! . .
You will see all the evidence you need to convince you that B and W Scratchers and Centralizers have conditioned the hole . .
For a GOOD CEMENT JOB
B and W Inc.
Well Completion Specialists
GULF COAST
Box 5266
Houston 12, Texas
Phone WE-6603
WEST COAST
Box 3751
Los Angeles 54, Calif.
Phone ME-4-1106

MEET the AUTHORS

F. H. CALLAWAY is reservoir engineering supervisor for Stanolind Oil & Gas Co. at the Tulsa general office. He joined Stanolind after receiving his BS degree in petroleum engineering from the University of Texas in 1946.

JAMES W. WHALEN has been associated with Field Research Laboratories of Magnolia Petroleum Co. as a senior research chemist since 1950. He holds a PhD degree in physical chemistry from the University of Oklahoma.

F. M. STEWART is staff petroleum engineer for Stanolind at their general office in Tulsa. He is a 1940 graduate in mining engineering of Missouri School of Mines. Since that time he has been with Stanolind, having some six years petroleum engineering experience in the Rocky Mountain region.

J. WADE WATKINS is a senior chemical engineer and chief of the Applied Research Section, Secondary Recovery Branch, Region VI, Bureau of Mines. The 1938 graduate of the University of Wichita, worked for Vickers Petroleum Co., Inc., at Potwin, Kans., following his graduation until 1943. Since that time he has been with the Bureau of Mines.

ROBERT E. GLADFELTER received his BA degree in physics and mathematics from Kansas State Teachers College and his MA degree in physics from Ohio State University in 1949. Since that time he has been engaged as a research engineer in problems of oil reservoir behavior for Stanolind Oil & Gas Co.

E. S. MARDOCK has been with Well Surveys, Inc., of Tulsa since 1948. The Stanford University graduate in chemistry accepted a position in the research laboratory of Shell Development Co. in 1937. In 1947 he became the area logging engineer for Shell in Midland.

RALPH V. HIGGINS holds a BS degree from the University of Denver and an MS degree from the University of California. He worked for two years with Tide Water Associated Oil Co. after graduation before joining the Bureau of Mines. He is now a petroleum engineer in the Fuels Technology Division of Region III, Bureau of Mines.

LESLIE J. NOAKER took his bachelor's degree at the University of Michigan, 1948-1952. During the 1952-1953 school year he held the Standard Oil Co. of California Fellowship at the University while earning his master's degree and conducting the research reported in the paper. He is currently employed by the Sun Oil Co. at Toledo.

DONALD L. KATZ is professor of chemical engineering and chairman of the Department of Chemical and Metallurgical Engineering at the University of Michigan. He started the Production Research group at the Phillips Petroleum Co., 1933-1936, after receiving his PhD from the University of Michigan. Since returning to the University in 1936, he has published papers regularly in AIME journals on such subjects as estimating reserves, gas hydrates, viscosity of gases, surface tension of crude oils, phase equilibria, and flow through porous media. The current paper is his twenty-seventh contribution to the AIME.

Local Section Activities

After a recess during the summer months, most of the Petroleum Branch Local Sections resumed their normal meeting schedule in September.

The **Dallas Local Section** held a Fall Round-up Stag Barbecue which began at 4 p.m. and lasted into the evening of September 11. Games and a barbecue dinner were featured.

At Tulsa the **Mid-Continent Local Section** also had a round-up meeting on September 17 and encouraged all members to bring guests.

W. F. Ellis, district petroleum engineer of Union Producing Co., spoke on "Drilling with Gas in the Black Warrior Basin" before the **Mississippi Section**. Officers were also elected at the September 9 meeting.

A paper on "Application of Conoco M-1 Mud to Rocky Mountain Operations" by J. L. Popham of Continental Oil Co. was presented at the **Denver Petroleum Section** on September 1. A business meeting concerning the change of the jurisdiction of the Denver Petroleum Section was also held at that time.

Many AIME members of the **Lou-Ark Section** attended a meeting of the Louisiana Engineering Society on September 8. The occasion was a talk on "The Engineering Registration Act, State of Louisiana, Its Inception, Its Effectiveness, and Proposed Amendments and Future Broadening Plans" given by Frank W. Macdonald, president of the Louisiana Engineering Society.

"A Symposium on Methods of Reserve Calculations" was held by the **Pacific Junior Group** on September 9. Nick van Wingen, consultant, discussed the material balance method; Rufus Clark explained the decline curve method; and Jan Law, consultant, covered the volumetric method. The purpose of the meeting was to provide the most complete survey of reserve estimation information for the practicing petroleum engineer that could be assembled. ★★★

Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 800 Fidelity Union Bldg., Dallas 1. These replies will be forwarded unopened and no fees are involved.

PERSONNEL

☆Petroleum Engineer, young graduate mechanical engineer liscensed as petroleum engineer in Texas desires position with major or independent operator in Southwest which offers opportunities and challenges. Has wide experience in drilling and production. Presently employed as equipment engineer with research institute. Code 221.

☆Reservoir Engineer with five years' experience in gas and water injection, workovers, and reserve estimation desires location in Southwest. Code 222.

POSITIONS

☆Corrosion Engineer, 30-35, for career opportunity in Venezuela with major oil company. Must have degree in chemical, mechanical, or electrical engineering with previous cathodic and general corrosion experience. Will also consider applications from candidates with less experience for positions as assistant corrosion engineers. Salary open. Write or apply in person to 725 Shell Building, Houston.

☆Petroleum Engineers, major oil company in South American has attractive positions for graduate engineers. Single status preferred. Production experience helpful but not necessary. Opportunities for advancement. Other added perquisites in addition to base salary. Reply giving full details of age, experience, college transcript, military status, etc., Code 563.

☆Petroleum Engineer, preferably recent graduate, for Louisiana Gulf Coast work. Duties to require assistance in preparation of reservoir studies, evaluation, and routine engineering reports. Work with reliable and financially strong concern. Reply giving age, previous experience, military status, and salary desired. Inquiries will be kept strictly confidential. Our employees know of this ad. Code 564.

The panel taking part in the water-flood discussion at Odessa were, standing left to right: C. C. Knoblic, L. H. Sullivan, chairman of the API Study Committee on Water Treatment; and George Buckles, chairman of the API Study Committee on Injection Well Treatment and Completion. Seated, left to right, are: H. L. Bilhartz, chairman of the South Central Region of the NACE; Bob Warden, vice-chairman of the Permian Basin Section, NACE; and Leon Crittendon.

WATER FLOODING DISCUSSION IN ODESSA ATTRACTS 380

At a joint meeting of five Permian Basin organizations in Odessa on August 9, 380 engineers heard a panel discussion on water-flood problems. Plans were discussed for a future water-flood school in West Texas.

Moderator of the discussion was H. L. Bilhartz, of Production Profit, Inc., Dallas. Panel members were: Leon Crittendon, Humble Oil & Refining Co., Midland; George Buckles, Buckles and Hostetler, Monahans, Tex.; C. C. Knoblic, consultant, Tulsa; and J. H. Sullivan, The Atlantic Refining Co., Dallas.

Organizations taking part in the meeting were: National Association of Corrosion Engineers, the sponsor; Petroleum Branch, AIME; Texas Society of Professional Engineers; American Society of Civil Engineers; and the Permian Basin Water Flood Association.

AIME-Socony Vacuum Scholarship Won By Texas A&M Student, Albin J. Zak, Jr.

Albin J. Zak, Jr., of Texas A&M, has been declared the winner of the annual AIME-Socony Vacuum scholarship. He will receive a total grant of $750 to complete his undergraduate study in petroleum engineering.

Paul Andrews, chairman of the Student Activities Committee, stated concerning Zak: "In addition to extremely high scholastic achievement Mr. Zak's record exhibits an outstanding recognition of social consciousness and service to others as evidenced by numerous extracurricular activities on the campus; by his election to honorary societies and membership in professional clubs; and by his service to the Boy Scouts during all four years of his college career."

"As is usual with these contests, every candidate is outstanding and worthy of the award," Andrews stated. "The choice of the Committee was a most difficult one."

AIME TO PAY TRAVEL COSTS FOR '55 SECTION DELEGATES

As in past years, the AIME will pay the round-trip first class rail and roomette cost of travel of section delegates to the Annual Meeting in Chicago next February. If travel is by air or other means, the amount of the rail fare will be allowed.

This decision was made at a joint meeting of the Executive and Finance Committees in July. At that time letters from M. B. Penn, chairman-elect of the Council of Section Delegates, and Fred J. Meek, current chairman of the Council, were presented. Both strongly recommended that traveling expenses of the delegates to the meeting of the Council of Section Delegates be paid in 1955.

The Committee voted to "continue the practice as to travel expenses, but without commitment as to the amount of rebate to be paid for 1955."

Last February at the Annual Meeting the Inter-Branch Council had recommended, when a rebate of $1 was being considered, that payment of travel expenses by the AIME might be eliminated and that the local sections could handle these expenses through the increased rebate which they received. The rebate to local sections was established as 50 cents per member for 1954.

The amount or formula for other financial support of local sections in 1955 will be determined by the Board of Directors at the Annual Meeting.

SAVE TIME!

Register in Advance

for the

Petroleum Branch

Fall Meeting

Send your registration today to avoid the registration lines and to be assured of getting tickets to all activities. Registration forms were sent to all Petroleum Branch members in the United States on September 10. They must be mailed back to the Petroleum Branch office by September 30.

Student Activities Reviewed as

DALLAS OFFICE PREPARES to HANDLE STUDENT ASSOCIATE APPLICATIONS, OFFER NEW SERVICES

All applications for Student Associate membership in the Petroleum Branch, AIME, will be handled through the Dallas office in the future. The Petroleum Branch, being very interested in strengthening its Student Chapters, plans to expedite the handling of all student applications and to offer Student Associates new services.

With the 1954-55 school year close at hand, a look at the 1953-54 activities of the Petroleum Branch Student Chapters indicates that they were extremely active during the year. Each chapter, responding to a questionnaire sent out by this office reported a successful year.

Largest Student Chapter

The largest Student Chapter of them all was at the University of Oklahoma, where 131 members met twice monthly to hear industry speakers. W. F. Cloud is the sponsor of this group, and W. C. Sutherland was their president during the past year.

The University of Texas Chapter, 105 strong, met twice monthly also. W. E. S. Dickerson, II, was their president, and H. H. Power, the sponsor. An industry speaker was featured at each meeting, with picnics and special outings scheduled several times during the school year.

The University of Tulsa Chapter met once a month during the past school year and boasted a membership of 104. General interest technical topics were the programs that drew large crowds to the meetings of this Chapter. Each year selected students from this group are sent to sectional and divisional meetings of the AIME and API. Ralph Cox was their president and A. W. Walker the Chapter sponsor.

Steady Growth

Pennsylvania State University Chapter reports a steady growth in recent years to a 1953-54 membership of 100. Their usual meeting last year followed the schedule of a business report, an industry speaker, and refreshments. Ward Wheatall was the 1953-54 president of the group, with John C. Calhoun the sponsor.

The Louisiana State University Chapter met once a month, featuring speakers and technical movies. Charles V. Moseley is their past president and B. C. Craft their sponsor. Throughout the year this 46-man chapter brought displays to the Engineering Building in the form of packers, cutting tools, pulling tools, hydraulic jars, etc.

The Texas Tech Chapter again last year sponsored the Petroleum Department's project in the annual Engineering Show and the float in the Homecoming Parade, in addition to their regular monthly meetings. Donald W. Moore presided over this Chapter of 46, and W. T. Ducker again served as their sponsor.

Symposium Sponsored

The big event of the academic year for the University of Houston Student Chapter was the Symposium on Permanent Well Completions in January, sponsored jointly by the Gulf Coast Local Section and the Chapter. Approximately 1,400 attended the event held on the University campus. This Chapter, with 40 members, met twice a month from 11:30 a.m. to 12:30 p.m., during the student activities hour. Four to six field trips are held yearly under the sponsorship of C. V. Kirkpatrick. Robert L. Barton was the president of the Chapter during the last academic year.

A membership of 20 was very active in the University of Southern California Chapter. Monthly meetings or field trips were held throughout the school year. The Annual Spring Meeting which is held jointly with the Pacific Petroleum Chapter and features morning, afternoon, and evening sessions is the highlight of each year. Presentations include student paper judging in the morning, talks by industry leaders in the afternoon, and a dinner and speaker in the evening. The group also sponsors the Annual Symposium on Clays and Drilling Muds. Richard H. Butler was their president and Carrol M. Beeson continued as sponsor.

More Publicity Desired

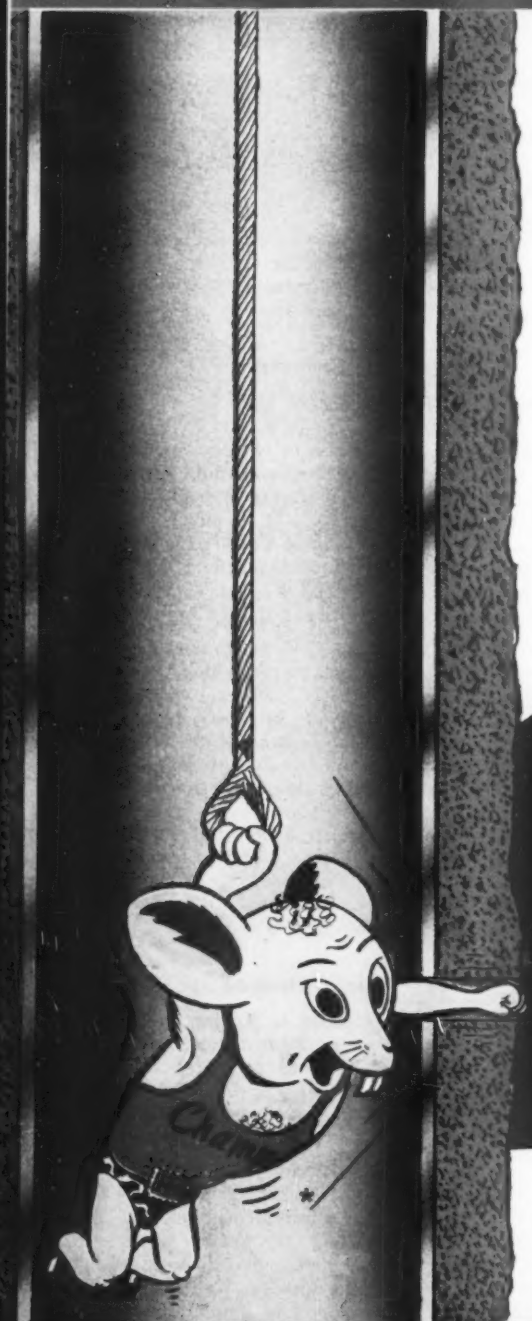
Louisiana Polytechnic Institute is starting a Student Chapter this academic year for the first time. Last year their 60-man club functioned in the same manner as a student chapter with Glenn Lee Corrigan as the sponsor. J. D. Marion, a Student Associate, was their president.

This year the Petroleum Branch office in Dallas wishes to be notified of the names of presidents of each Student Chapter. These presidents will be sent information helpful in planning their chapter activities, including a listing of the talks given before each Petroleum Local Section. The JOURNAL OF PETROLEUM TECHNOLOGY editors wish to receive more information on Student Chapter activities for publication in the magazine, also.

Throughout the Student Chapters the sponsors and officers of each group are doing an important job in introducing the petroleum engineers of tomorrow to their professional society. Their continued success is assured in the 1954-55 school year. ★★★

Meet MIGHTY MOUSE*... *"Champ of the Midget Guns!"*

PGAC's Expendable Jet Perforator for permanent-type well completions



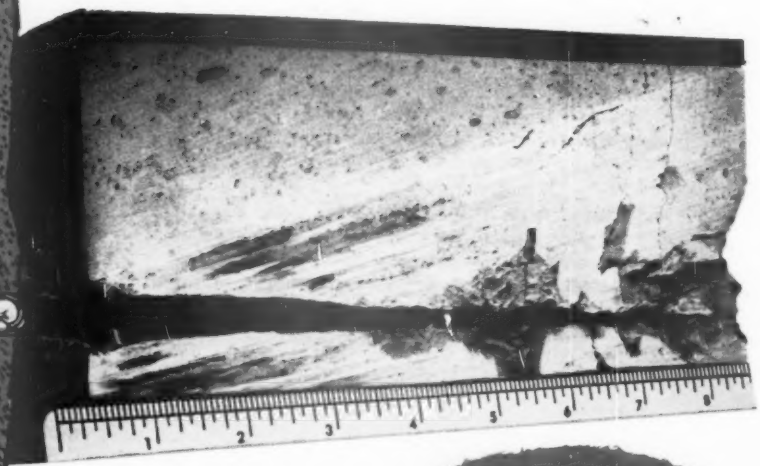
In recent tests conducted by a major oil company on competitive perforators for permanent-type completions, PGAC's "MIGHTY MOUSE" repeatedly produced *penetrations over 50% deeper . . .* also *cleaner holes,* with diameters 50% to 100% larger. That's why Mighty Mouse so often succeeds after other tubing-type perforators have failed.

Champ's Angle A Winner!

MIGHTY MOUSE shoots on a 90° horizontal, straight out into the zone. Thus, all penetrating power is fully utilized for *effective* penetration—instead of being wasted on 45° diagonal shooting. Thus, too, all shots from Mighty Mouse produce more effective penetration *all around the casing*—instead of on one side only.

Champ's Wallop A Knockout!

Tests prove that PGAC's NEW Jet Shots in the 1¾" O.D. Mighty Mouse penetrate almost as deep as conventional 4" O.D. jet perforators. Mighty Mouse's adjacent shots are spiraled 30° apart, six shots to the foot, giving more perforations per foot than any other midget gun. Assembled in any length, it shoots any number of perforations desired. Write today for complete data.



1 3/4" Mighty Mouse penetrates 7 1/4"—through 3/8" steel plate and into 7-day neat cement. Note large, clean entrance hole (15/32" diam.)

*Trade Mark

For greater production from permanent-type completions . . . always call for MIGHTY MOUSE!

PGAC 54B

PGAC PERFORATING GUNS ATLAS CORPORATION

Houston, Texas Telephone: LYnchburg 4161

General Offices: 3915 Tharp St. — Sales Office: Melrose Bldg. — Main Plant: 7730 Scott St.

31 PGAC OFFICES ALWAYS READY TO SERVE YOU . . . CALL THESE TELEPHONE NUMBERS FOR PROMPT SERVICE

TEXAS: Houston, LYnchburg 4161 — Corpus Christi, 3-1324 — Dallas, RAndolph 2943 — Longview, Plaza 9-4486 — Alice, 4-3424
Abilene, 2-4172 — Gainesville, 2517 — Odessa, 6-6429 — Beaumont, 2-4263 — Victoria, 1023 — Graham, 1728.
LOUISIANA: Shreveport, 3-1648 — Lake Charles, 4724 — Lafayette, 4-2396. KANSAS: Great Bend, 4306 or 4307. NEW MEXICO: Hobbs, 3-2015.
OKLAHOMA: Oklahoma City, CEntral 2-5342 — Pauls Valley, 1577 — Seminole, 2938 — Healdton, 77 — Ardmore, 857.

AFFILIATE COMPANIES: CANADA—Perforating Guns of Canada, Ltd.; Edmonton, Alberta
GERMANY—Atlas Deutsch-Amerikanische Olfelddienst G. m. b. H.; Kiel

AMERADA
BOTTOM HOLE RECORDING PRESSURE AND TEMPERATURE GAUGES

Across the nation — around the world — the Amerada Pressure Gauge is still the standard.

You are cordially invited to visit our display booth No. 31, Plaza Hotel, San Antonio, Texas, at the October 17-20 A.I.M.E. meeting and discuss your gauge problems.

GEOPHYSICAL RESEARCH CORPORATION

2607 North Boston Place

Tulsa, Oklahoma

PROFESSIONAL SERVICES

This space available only to AIME members. Rates Upon Request

AMSTUTZ AND YATES, INC.
Petroleum Engineers and Geologists
Estimates of Oil and Gas Reserves
Property Valuations, Reservoir Analyses
Geologic Investigations
406 KFH BLDG., WICHITA 2, KANS.

BALL ASSOCIATES
OIL AND GAS CONSULTANTS
Max W. Ball — Douglas Ball
Rex E. Cheek — Taber de Polo
1025 VERMONT AVENUE, N.W.
WASHINGTON, D.C.

J. HOWARD BARNETT
PETROLEUM CONSULTANT
Casper National Bank Bldg. Phone 2-1758
113 East Second St. Casper, Wyoming

ROBERT M. BEATTY
Consulting Geologist
Esperson Building Houston 2, Texas

W. RUSSELL BIRDWELL
Consulting Petroleum Engineer
PHONE 6-6601 BOX 1348
Frontier Oil & Gas Bldg.
McALLEN, TEXAS

BRADLEY, OLIVER AND ASSOCIATES
PETROLEUM CONSULTANTS
Geology, Engineering and Management
3300 Republic Bank Bldg.
Dallas, Texas ST-5331

Oil and Gas Reserves — Appraisals
Flooding — Technology
J. RANDOLPH BUCK
Petroleum Engineer
National City Bldg. STerling 1688
DALLAS, TEXAS

JOHN G. CAMPBELL
Analytical and Petroleum Chemists
Podbielniak and Charcoal Analyses
Waters - Oil Field Brines
Field Sampling
PHONE: 4-3071 CORPUS CHRISTI, TEXAS

CHEMICAL & GEOLOGICAL LABORATORIES
Consultants - Investigations - Evaluations
James G. Crawford.....Chemical Engineer
H. F. Summerford.....Petroleum Geologist
George W. Davis, Jr.....Petroleum Engineer
P. O. BOX 279 CASPER, WYOMING

CRUTCHFIELD AND PRUETT
CONSULTING PETROLEUM ENGINEERS
Wilson Tower
CORPUS CHRISTI, TEXAS
John W. Crutchfield — *Horton T. Pruett*

EARLOUGHER ENGINEERING
Petroleum Consultants - Core Analyses
Specializing in Secondary Recovery
Investigations - Appraisals - Operations
3316 East 21st St.
TULSA 5, OKLAHOMA
Phone: 9-6345

EASTON & SACRE
Consulting Petroleum Engineers
E. M. Easton
L. P. Sacre, Jr.
H. M. Allen
1660 Oak Street Phone FAirview 2-3934
BAKERSFIELD, CALIFORNIA

WARD M. EDINGER
Consulting Petroleum Engineer
Secondary Recovery
Oil and Gas Reserves
Reservoir Analyses
729 Hightower Building
Oklahoma City, Okla. FO-5-1421

FITTING & JONES
Engineering and Geological Consultants
Ralph U. Fitting, Jr.
J. R. Jones
T. W. Hassell
Petroleum — *Natural Gas*
223 S. Big Spring St. Box 1637
Phone 4-4451 Midland, Texas

ROBERT D. FITTING
Petroleum Consultant
Engineering and Geology
MIDLAND, TEXAS
201 West Building Phone: 4-4922

MICHEL T. HALBOUTY
CONSULTING GEOLOGIST
AND PETROLEUM ENGINEER
Shell Building
Houston 2, Texas Phone PR-6376

E. W. HOUGH
Emulsion and Paraffin Problems
Box 7547 University Station
Austin, Texas

KELLER & PETERSON
Petroleum Consultants
Reserve Estimates — *Reservoir Analysis*
Petroleum and Geological Engineering
902 W. T. WAGGONER BLDG.
FORT WORTH, TEXAS
Phone: FOrtune 4340
W. O. Keller — L. F. Peterson

R. W. LAUGHLIN
Well Elevations
Laughlin-Simmons & Co.
2010 S. Utica
TULSA 4, OKLAHOMA

MARTIN, WILLIAMS & JUDSON
PETROLEUM CONSULTANTS
Engineering - Geology - Management
131 Central Bldg. Phone 2-5216
MIDLAND, TEXAS
William H. Martin — R. Ken Williams
Edward H. Judson

WAYNE L. McCANN
Petroleum Engineering and Geology
SHREVEPORT, LOUISIANA
Petroleum Building Phone: 2-8023

M. M. MONTGOMERY
CONSULTING PETROLEUM ENGINEER
Valuations, Drilling, Well Completions,
Production, Workovers
Property Management
Hapip Bldg. Williston,
3-4642 North Dakota

JOHN A. NEWMAN
Reserve Estimates, Property Valuation
Reservoir Analysis
319 Gulf Building Houston 2, Texas

NOWLAN-DODSON ENGINEERING, INC.
Reservoir Analyses — Water Flood Projects
Natural Gas Engineering
Gas Storage Reservoirs
EVANSVILLE, INDIANA
319 COURT BUILDING PHONE 5-8154

OILFIELD RESEARCH
Core Analysis — Evaluation
Development of Water Flood Projects
Operation of Water Flood Projects
EVANSVILLE, INDIANA
1907 Division Street
PHONES: 6-5591 (Night, 6-4882 or 6-0608)

ERNEST K. PARKS
CONSULTING PETROLEUM ENGINEER
Planning, Direction and Examination of Oilfield Operations, Estimates of Oil and Gas Reserves, Oil Property Valuation
306 N. Cliffwood Ave., Los Angeles 49, California
Telephone: Arizona 34832

PETROLEUM CONSULTANTS
Engineering and Geology
E. O. Bennett — James O. Lewis
D. G. Hawthorn — M. D. Hodges
1552 Esperson Building Houston 2, Texas

PETROLEUM ENGINEERING INCORPORATED
Petroleum and Geological Engineering
Core Analysis — Appraisals
Development and Operation of
Water Flood Projects
ROBINSON, ILLINOIS BOX 239

PETROLEUM TECHNOLOGISTS
Production Research — Core Analysis
Secondary Recovery
868 Truckway, Montebello, Calif.
NORRIS JOHNSTON PArkview 1-5338

PISHNY AND ATKINSON
Engineers and Geologists
Valuation of Oil and Gas Properties
2412 Continental Life Bldg.
FORT WORTH, TEXAS
Chas. H. Pishny Burton Atkinson

HARRY H. POWER
PETROLEUM AND VALUATION ENGINEER
Box 1542 University Station
Austin, Texas

E. E. REHN
Consulting Petroleum Geologist
Oil Exploration
Wood Building, 624 Locust Street
EVANSVILLE, INDIANA

R. WAYNE RUSSELL
PETROLEUM CONSULTANT
Geology, Engineering and Management
625 Reserve Loan Life Bldg., Dallas, Tex., Phone ST-3020

JOHN HOWARD SAMUELL
Specializing in Bank Valuations
Geologist and Petroleum Engineer
Compton Building Box 732
Phones 4-4493 and 4-4597, Abilene, Texas

SOL SMITH
CONSULTING ENGINEER
PETROLEUM AND NATURAL GAS
Reserves Deliverability
Oil and Gas Proration
913 BROWN BUILDING
AUSTIN, TEXAS PHONE: 8-9498

WM. H. SPICE, JR.
Consulting Geologist
2101-03 Alamo National Building
SAN ANTONIO 5, TEXAS

SUBSURFACE ENGINEERING COMPANY
Experts in Field Testing, Sampling and Analyzing Reservoirs and Reservoir Fluid for Reservoir Studies.
WRIGHT PETROLEUM LABORATORY
Home Office: Box 1827, Tulsa
Frank Purdum

TRAFFORD & ASSOCIATES
Geological, Petroleum Engineering and Management Consultants

		Phones
E. Trafford		
R. Pat	Wales Hotel Bldg.	692591
J. B. Newland	10th Floor	61212
K. R. Stout	Calgary, Alberta	61224

CHARLES C. (RUSTY) WILLIAMS
Geologist — Geophysicist
Williams Seismograph, Inc.
252 South Green Street Phone 62-7274
WICHITA, KANSAS

NEED BACK ISSUES

The Petroleum Branch office is interested in purchasing copies of two past issues of the JOURNAL OF PETROLEUM TECHNOLOGY in order to complete the office files. These issues are the February, 1938, and January, 1946, numbers, which were published by the New York office in the 6 x 9 in. size.

The office is also interested in purchasing the 134-page pamphlet entitled "Symposium on Petroleum and Gas," which was issued with *Mining and Metallurgy* in April, 1923.

Dallas Section Starts Electric Logging Study

The first of eight Study Group sessions on well logging interpretations was held by the Dallas Local Section on September 9. G. T. Armstrong, of Halliburton Oil Well Cementing Co., led the discussion on "Theory of Resistivity Measurements Using Conventional Electric Logs."

The Study Group will cover conventional electric logs, self potential curves, quantitative analysis of in place saturations, determination of in place porosity, and the theory and interpretation of radioactive logs in subsequent sessions.

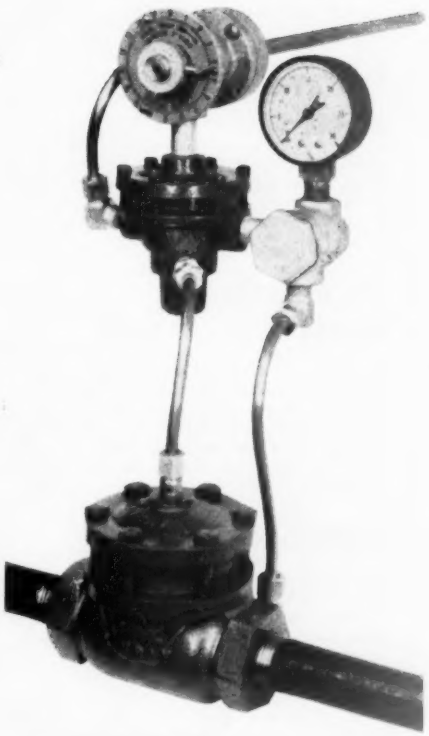
Kimray Temperature Controller
Multi - Purpose

APPLICATIONS:

To Control Temperature of Gas Fired:

(1) Emulsion Treaters
(2) Oil Heaters
(3) Gas Heaters
(4) Steam Generators

To Control Flow of Anti-Freeze Fluids From Injection Pumps.



FEATURES:

THERMOSTAT
Non-Bleed Pilot — No Orifices to Adjust.
Snap Acting; furnished as standard.
Throttling; available if specified.

Accuracy:
T-12 - 4° to 5°F variation
T-18 - 3°F variation

Control Range:
Approximate —30°F to 375°F

Pressure:
Supply; 3 lb. minimum to 30 lb. maximum
Working; 500 lb. without socket, 3000 lb. with socket

BURNER VALVE
Soft seat insures tight shut-off.
Full line size seat; ¾" or 1".
Stainless trim.

Manufactured By **KIMRAY INC.** Oklahoma City U. S. A.

DISTRIBUTORS:

HOUSTON, TEX.—Clif Mock Co.
LAKE CHARLES, LA.—Clif Mock Co.
LAFAYETTE, LA.—Clif Mock Co.
NEW IBERIA, LA.—Clif Mock Co.
BEAUMONT, TEX.—Clif Mock Co.
LOS ANGELES, CALIF.—Fred P. Koenig Co.
ODESSA, TEX.—Control Equipment, Inc.
ABILENE, TEX.—Control Equipment, Inc.
SAN ANGELO, TEX.—Control Equipment, Inc.
HOBBS, N. M.—Control Equipment, Inc.
CORPUS CHRISTI, TEX.—Engineering Service Co.
SHREVEPORT, LA.—Merla Tool Corp.
OKLAHOMA CITY, OKLA.—Kimray, Inc.

Well Surveying is our Business-

OUR ONLY BUSINESS

When you want a well surveyed—up, down or sideways—call on Sperry-Sun where for 24 years we've done nothing but survey wells and develop new methods and instruments to do the job better and better. When you want a straight hole job, a cased job, or a progressive job for directional drilling we've got the men and equipment to do the job faster, better and at less expense. Sperry-Sun has 12 offices, located to serve every active area. Put your call in now for full information for the rental of an accurate, efficient instrument, or for the Sperry-Sun Service Crew.

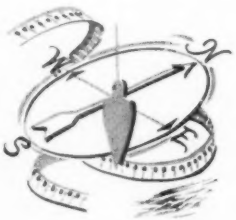
SPERRY-SUN E-C INCLINOMETER

Measures inclination from 0°—10° for "straight hole" drilling. Available on rental plan.

SPERRY-SUN SINGLE SHOT

Measures inclination and direction from 0°—90° for surveying uncased holes or below casing by running on a line or in a K-Monel Collar. Available on rental plan.

SPERRY-SUN MAGNETIC MULTI SHOT



Measures inclination and direction from 0°—90° at any interval. Makes up to 1,000 records per run. Used for surveying uncased holes or below casing by running on a line or in a K-Monel Collar. A Sperry-Sun crew is at your service anywhere.

SPERRY-SUN SURWEL

Gyrocompass surveying of cased or uncased holes. Measures inclination and direction from 0°—60°. Makes complete record of entire hole at one trip—as many as 2000 individual readings. Sperry-Sun crew is at your service anywhere.

SPERRY-SUN OFFICES

Houston • Falfurrias • Odessa • Marshall • Abilene, Texas—Oklahoma City, Oklahoma—Lafayette • New Orleans, Louisiana—Long Beach • Ventura • Bakersfield, California—Casper, Wyoming

SPERRY-SUN WELL SURVEYING COMPANY

3118 Blodgett Avenue • Houston, Texas

Local Section Meeting Schedule

BILLINGS PETROLEUM SECTION: Meets in Billings, Mont. *Chairman*, H. R. Lowe, Wallace & Lowe, Inc., Billings. *Secretary*, J. G. Yapuncich, Yapuncich-Sanderson Lab., Billings.

DALLAS SECTION: Meets third Monday each month in Dallas. *Chairman*, G. R. Brainard, Jr., Lucerne Corp., Dallas. *Secretary*, A. B. Dyes, The Atlantic Refining Co., Dallas.

DELTA SECTION: Meets second Tuesday each month in New Orleans. *Chairman*, A. L. Vitter, California Co., New Orleans. Secretary, W. D. Clift, Humble Oil & Refining Co., New Orleans.

DENVER PETROLEUM SECTION: *Chairman*, T. O. H. Mattson, The Texas Co., Denver. *Secretary*, A. J. Carter, Jr., Bay Petroleum Corp., Denver.

EAST TEXAS SECTION: Meets second Tuesday each month at Gregg County Airport. *Chairman*, G. L. Scheirman, Shell Oil Co., Kilgore. *Secretary*, T. A. Banta, Lufkin Foundry & Machine Co., Kilgore.

FORT WORTH SECTION: Meets third Tuesday each month in Fort Worth. *Chairman*, M. I. Taylor, Gulf Oil Co., Fort Worth. *Secretary*, B. J. Bonner, T & P Coal and Oil Co., Fort Worth.

GULF COAST SECTION: Meets third Tuesday each month in Houston. *Chairman*, W. B. Hopkins, Gulf Oil Corp., Houston. *Secretary*, Herman A. Engel, Jr., Union Sulphur and Oil Co., Houston.

HOBBS PETROLEUM SECTION: Meets in Hobbs, N. M. *Chairman* W. G. Abbott, Amerada Petroleum Corp., Monument. *Secretary*, John Yuronka, Jr., Texas Pacific Coal & Oil Co.

HUGOTON LOCAL SECTION: Meets in Liberal, Kans., and Guymon, Okla. *Chairman*, Jack Phillippe, Panhandle Eastern Pipe Line Co. *Secretary-Treasurer*, C. P. Pyeatte, Republic Natural Gas Co., Hugoton.

ILLINOIS BASIN CHAPTER: Meets first Thursday each month in Salem, Ill. (No meetings in July and August.) *Chairman*, D. M. Moon, Schlumberger, Mt. Vernon. *Secretary*, George H. Link, Carter Oil Co., Carmi, Ill.

KANSAS SECTION: Meets second Wednesday in Wichita and fourth Thursday in Great Bend. (No meetings in June, July, and August.) *Chairman*, John T. Gary, Continental Oil Co., Wichita, Kan. *Secretary* A. E. Collins, Vickers Petroleum Co., Wichita.

LOU-ARK SECTION: Meets third Monday each month in Shreveport, La., *Chairman*, C. R. Olson, Ohio Oil Co., Shreveport. *Secretary*, E. P. Ogier, W. C. Spooner, Inc., Shreveport.

MID-CONTINENT SECTION: Meets second Monday each month in Tulsa: study group meets fourth Tuesday each month (Luncheon meetings each Thursday, Mayo Hotel.) *Chairman*, M. B. Penn, Mid-Continent Petroleum Co., Tulsa. *Secretary*, D. R. Johnson, Gulf Oil Corp., Tulsa.

MISSISSIPPI SECTION: Meets in Laurel, Jackson, and Natchez, Miss. *Chairman*, W. I. Sanderson, Halliburton Oil Well Cementing Co., Natchez, Miss. *Secretary*, Bill J. McEver, Lane-Wells Co., Natchez, Miss.

NEW YORK PETROLEUM SECTION: Meets in New York City monthly. *Chairman*, H. E. McAuliffe, Jr., Socony-Vacuum Co. *Secretary-Treasurer*, M. J. Sladic, Arabian-American Oil Co.

NORTH TEXAS SECTION: Meets second Monday each month in Wichita Falls. *Chairman*, D. B. Meisenheimer, Texas Co. Wichita Falls. *Secretary-Treasurer*, Joseph Saxon, Ryder-Scott Co., Wichita Falls.

OKLAHOMA CITY SECTION: Meets at noon third Thursday each month in Oklahoma City. *Chairman*, R. K. McIvor, Sohio Petroleum Co., Oklahoma City. *Secretary*, W. C. Pearson, Stanolind Oil & Gas Co., Oklahoma City.

PACIFIC PETROLEUM CHAPTER: Meets in Los Angeles. *Chairman*, Milton E. Loy, Schlumberger Well Surveying Corp., Los Angeles. *Secretary*, J. A. Klotz, California Research Corp., La Habra, Calif.

JUNIOR GROUP: Meets second Thursday each month at Turf Club in Rivera. *Chairman*, J. P. Garten, Long Beach Oil Development Co. *Secretary*, David K. Hayward, The Texas Co.

PANHANDLE LOCAL SECTION: Meets in Pampa, Tex. *Chairman*, Donald E. Radtke, Magnolia Petroleum Co., *Secretary*, Henry J. Rose, Cabot Carbon Co.

PERMIAN BASIN SECTION meets third Monday each month in Midland or Odessa, Tex. *Chairman*, J. R. Brack, Forest Oil Corp., Midland. *Secretary*, J. B. McClellan, Dowell Inc., Midland.

SAN JOAQUIN VALLEY SECTION: Meets first Tuesday alternate months (February-December) in Bakersfield, Calif. *Chairman*, Harry D. Campbell, Franko Western Oil Co., Bakersfield. *Secretary*, W. J. Taylor, Lane-Wells Co., Bakersfield.

SOUTH PLAINS SECTION: Meets third Thursday each month in Lubbock, Tex. *Chairman*, M. C. Gulledge, Magnolia Petroleum Co., Brownfield, Tex. *Secretary*, Philip Johnson, Texas Tech., Lubbock.

SOUTHWEST TEXAS SECTION: Meets third Wednesday each month in Corpus Christi: (No meetings in July, August, December.) *Chairman*, Chester L. Wheless, La Gloria Corp. *Secretary*, Robert R. Wallace, Seaboard, Corpus Christi.

WEST CENTRAL TEXAS SECTION: Meets third Wednesday each month in Abilene. *Chairman*, Dalton Moore, Jr., Wimberly Field Unit, Abilene. *Secretary*, Harold Lacik, Warren Petroleum Corp.

WYOMING SECTION: Meets in alternate months in Casper. *Chairman*, M. O. Hegglund, Stanolind Oil & Gas Co., Casper. *Secretary-Treasurer*, Fraser Burback, Socony-Vacuum Co., Pagasus Division, Casper.

AVAILABLE JOHNSTON by AL CAPP

IS YO' JOHNSTONS AVAILABLE, T'TEST MAH NEW LOVE-SEAT?
WE IS AVAILABLE, **ONLY** FO' DRILL-STEM TESTIN'!!
—AN' WE DOES IT, WIF A MINNY-MUM O' **DOWN TIME.!!**

C 546

Copr. Capp Enterprises 1954

JOHNSTON TESTERS

first in drill stem testing

HOUSTON, TEXAS

LOS ANGELES, CALIF • CALGARY, CAN.

FORMATION AND CASING TESTING — JOHNSTON

Proposed for Membership, Petroleum Branch

TOTAL AIME membership on June 30, 1954, was 21,033; in addition 1,697 Student Associates were enrolled.

PETROLEUM BRANCH ADMISSIONS COMMITTEE

F. G. Prutzman, chairman; J. H. Sullivan; F. C. Kelton; C. C. Harter; Virgil Harris; Charles Hudson.

INSTITUTE ADMISSIONS COMMITTEE

O. B. J. Fraser, chairman; R. B. Caples, vice-chairman; F. A. Ayer, A. C. Brinker, R. H. Dickson, Max Gensamer, Ivan A. Given, Fred W. Hanson, T. D. Jones, Sidney Rolle, J. H. Scaff, John T. Sherman, F. T. Sisco, Frank T. Weems, R. L. Ziegfeld.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member, A, Associate Member; S, Student Associate.

Arkansas
Lewisville — Saylor, William Morris (M).

California
Bakersfield — Monroy, Mario Rodolfo (J).
Costa Mesa — Watson, John Stuart, Jr. (J).
Santa Barbara — Ellis, James H. Northrop (R, C/S-J-M).

Colorado
Denver — Frazier, Roger Sheldron (M); Paine, Samuel M. (J).

Illinois
Crossville — Piland, Glen Albert (J).
Robinson — Bulla, Robert (R, C/S-S-M).

Indiana
Evansville — Penrod, John Melvin (R, M).

Kansas
Independence — Lancaster, William Richard (R, C/S-S-J).
Lyons — Queen, John Adolph (C/S-J-M).

Massachusetts
Cambridge — Michaels, Alan Sherman (M).

Montana
Billings — Autry, Mark Paul (J); Fair, Robert Arthur (J); Hudson, William Taylor (M).

Nebraska
Sidney — Essley, Philip LeRoy, Jr. (J).

Ohio
Findlay — Poe, George Frick (M).

Oklahoma
Bartlesville — Krutsinger, Virgil W. (R, J).
Duncan — Hathorn, Don Hugh (M).
Oklahoma City — Coogan, John Creig (M); Grady, James Ernest (M); Spangler, Carl David (J); Weaver, Billy Ray (R, C/S-J-M).
Pauls Valley — Lindsey, Bill J. (J).
Tulsa — Fulton, Robyn Paul (M).
Wirt — Harrison, John Frank (J).

Texas
Abilene — Hammer, Wallace Lenord (J); LaRue, Chester Raymond (M); Nugent, Walter Karrison (M).
Bellaire — Jung, Robert Arthur (M); McGonagill, Frank Ellis, Jr. (M).
Corpus Christi — Etheredge, Morris L. (M); Hitt, Hugh Harlan (M).
Dallas — Higginbotham, George Truett (J); Smith, Jack Harold (T); Soltes, Elton David (M); Upchurch, James Oliver (M); Wolff, Ulrich R. (J).
Houston — Arnold, Charles William (A); Brooks, Fred A., Jr. (J); Burkhardt, Joseph Avery (J); Gaither, Orville Duane (J); Kern, Curtis Raymond (M).
Kilgore — Neely, Aaron Buford (J).
Longview — Brashear, Charles Aubrey (A).
Lubbock — Blackaller, Edward Harrison (C/S-A-M).
McAllen — Hardaway, Rex L. (J).
Midland — Crews, Orval Hardee (M); Leonard, James Edgar (A); Maverick, Phillip, Jr. (R, M).
Odessa — Czirr, Donald Leroy (J).
Old Ocean — Dixon, Buddy Ray (R, J).
San Antonio — West, Robert Van Osdell, Jr. (M).
Snyder — Jean, Joseph Wallace, Jr. (J).
Tomball — Ehrhardt, Charles David, Jr. (M).
Wichita Falls — Foster, Kenneth William (J).

Wisconsin
Madison — Bredeson, Duane Harold (J).

Wyoming
Worland — Hogan, Joseph Reed (M).

Canada
Calgary, Alta. — Bannantine, George Augustine (M).
Edmonton, Alta. — Dlugos, John William (J).

Colombia
Barrancabermeja — Ford, George Malcolm (J).

Mexico
Coatzacoalcos, Ver. — Rivero, Orlando Gomez (J).

Persian Gulf
Kuwait — Martin, Richard Ernest (M).

Venezuela
Caracas — Kunkel, Frederick William (J); Sheffield, Neil Jackson, Jr. (R, C/S-S-J).

PREDICTION of FLOODABILITY of OIL SANDS

Reported by C. R. McEwen

Norris Johnston, of Petroleum Technologists, Inc., Montebello, Calif., presented data obtained from 425 flood pot tests to the Pacific Petroleum Chapter Technology Forum Meeting recently. More than half of this laboratory information on water-flooding evaluation has been gathered since publication of a recent paper by Johnston and Nick van Wingen, "Recent Laboratory Investigations of Water Flooding in California," *Trans.* AIME (1953), 198, 219.

The purpose of the study of the data was to learn if among the many physical variables affecting oil recovery by water flooding a correlation exists which can be used to predict recovery, without resorting to a laboratory flood pot test. As yet, this goal has not been realized, it was concluded.

Johnston stated that the best correlation is obtained when oil recovered, in per cent of initial oil present, is plotted against oil in place in barrels per acre-foot. He interpreted this to mean simply that if there is a lot of oil present, it is possible that a lot can be recovered by water flooding. The data collected on flood pots which in this study produced oil represent some rather wide ranges in variables.

Geographically, the data covers fields in Texas and Wyoming, as well as seven California areas.

Depth	280-10,000 ft
Formation Temperature	90-203°F
Gravity	10.8-37° API
Viscosity	0.49-8,300 cp
Permeability	5-27,000 md
Oil mobility, (K/μ)	1-704 md/cp
Porosity	6-46 per cent
Initial Oil Saturation	as low as 4 per cent
Residual Oil Saturation	2-67 per cent
Initial Water Saturation	4-86 per cent
Initial Gas Saturation	1-59 per cent
Oil Recovery:	
Percent of Initial Oil	up to 86 per cent
Bbl/acre-ft	85-1,500
Fill-up, Per Cent of Pore Space	1-55

Johnston distinguished between data obtained on "raw floods," in which cores were flooded as received in the laboratory, and "reconstituted floods," in which the core material is shaped, extracted, and resaturated as in the conventional restored state method. The cores in a reconstituted flood undergo capillary desaturation using formation crude oil cut by a neutral solvent such as keorsene to duplicate formation viscosity. Data are more meaningful and correlations less scattered for reconstituted floods. For example, in the correlation mentioned above, raw floods gave a range of oil recovery from 7-66 per cent of initial oil, whereas in reconstituted floods recovery ranged only from 53-76 per cent.

A second correlation, somewhat less satisfactory, is obtained when oil recovered is plotted against initial oil saturation. Several other parameters were tried in the attempt to correlate them with oil recovery, but the results were in general not satisfactory. These attempts included:

Residual oil vs oil viscosity.

Residual oil vs oil mobility.

Unrecoverable oil (ratio of residual to initial oil saturation) vs viscosity.

Oil recovery vs initial water saturation.

Residual oil vs initial gas saturation.

Residual oil vs oil gravity.

Residual oil vs ratio of porosity to permeability.

Thus, as of today there is no single parameter or combination of parameters by which one can unequivocally predict oil recovery by water flooding, Johnston states. However, a number of general observations have been made: (1) residual oil saturations generally exceed 10 per cent; (2) successful laboratory floods have included oils with viscosities as high as 8,300 cp; (3) oil banks are encountered in reconstituted floods; (4) subordinate phase recovery of California crudes can be successful; and (5) residual oil contents are lower when gas is present.

Necrology

Date Elected	Name	Date of Death
1926	Paul T. Seashore	Apr. 11, 1954
1922	Edward Dixon	June 7, 1954
1943	Thomas W. Pew	Unknown
1935	Thomas Gayleon Andrews	July, 1954
1918	James O. Lewis	June 15, 1954
1918	Frederick LeV. Serviss	July 22, 1954
1920	George H. Taber, Jr.	Aug. 20, 1954
1927	Clifford S. Wilson	May, 1954
1937	Max W. Ball	Aug. 28, 1954

CHARLES C. (RUSTY) WILLIAMS recently sold his partnership interest in Seismic Engineering Co. of Dallas to form a new seismograph contracting firm, Williams Seismograph, Inc. The present address of the new organization is 252 South Green St., Wichita, Kan.

★

JOHN J. NEALE has been named president of Lane-Wells Co. He has been assistant to the president for the past year. He started to work for the company as a loader in Houston in 1936 and has served in almost every capacity with Lane-Wells in his climb to the presidency.

★

MARVIN F. OWENS has been named vice-president in charge of the new Oil and Gas Department of the Central Bank and Trust Co. in Denver. He has been chief petroleum engineer for Bay Petroleum Corp. for the last eight years. Prior to that he was with British-American Oil Producing Co. from the time of his University of Oklahoma graduation in 1937. During World War II he served as a lieutenant colonel in Army Ordnance.

★

LEONARD B. LIPSON, senior research physicist at Magnolia's Field Research Laboratories, Dallas, has been appointed an associate professor of petroleum engineering at the University of Houston. On September 1, he will assume his new position, which will include assisting in the development of a graduate program in petroleum engineering and conducting research in the field of core analysis and well logging.

★

JAMES H. HICKS has accepted the position of South Texas and Mexico district manager of Texas Gulf Tank Co. Formerly he was field salesman for Parkersburg Rig and Reel Co. He will continue to reside in Corpus Christi.

★

ARNOLD S. BUNTE has joined the staff of the Denver National Bank as consulting geological engineer. He will assist the bank in expanding financing services to the oil industry and will continue to hold his position as associate professor of geology at Colorado School of Mines at Golden.

★

RODNEY S. DURKEE has been named Chairman of the Board of Lane-Wells Co. He joined the company in 1938 after nearly 23 years in an executive capacity with major oil companies. In 1939 he was made president, and the company has grown to include nearly 100 branches since that time. He will have general supervision over company activities, replacing Walter T. Wells, co-founder of the company, who will now serve as founder-chairman of the company.

★

MARVIN GEARHART has been named head regional field engineer for Security Engineering Division, one of the Dresser Industries. He will supervise Security's regional field engineers in the Mid-Continent, Rocky Mountain, and Canadian oil fields. Prior to his recent promotion, he was the company's chief regional field engineer for the Western Region.

★

H. W. BENISCHEK is now on a one-year leave of absence from the University of Oklahoma to serve as visiting professor at Texas Technological College, Lubbock. He is the chairman of the School of Petroleum Engineering at Oklahoma.

BENSON M. (BENNY) KINGSTON has opened petroleum engineering and geological consulting offices in the Burch Hotel Building, Breckenridge, Tex. He resigned recently as assistant manager and technical advisor to The Chemical Process Co. He is a co-inventor and patent holder of a permeability survey and acidizing control system and of a mud-acid used to clean wells of drilling mud. Also, he is the author of *Acidizing Handbook* and of the North Texas report in the 1948 and 1949 AIME *Statistics* volume.

★

R. E. HEITHECKER, who was formerly with Seaboard Oil Co., has opened a consulting office at 6013 Martel Ave., Dallas. He will work as a consulting engineer in the fields of petroleum and natural gas. From 1926 until 1945 he worked with the Bureau of Mines at Bartlesville, then he joined Seaboard in Dallas. Through his recommendations a diamond core barrel was used in West Edmonds, Okla., field, which successfully recovered for the first time a core from a fractured limestone formation. In 1951 he was Petroleum Branch treasurer.

★

ROBERT L. WHITING has become head and DANIEL M. BASS, JR., assistant professor of the Texas A&M Department of Petroleum Engineering. Whiting holds a bachelor and masters degree in petroleum engineering from the University of Texas. Prior to coming to Texas A&M, he was employed as a petroleum reservoir engineer by the Stanolind Oil & Gas Co. at their Tulsa office. Bass worked after graduation as a petroleum engineer with Magnolia Petroleum Co. in their West Texas division. For the past two years he has been employed by the Texas Petroleum Research Committee, where he has done research problems related to increasing oil recovery.

Our Face is Red!

We never dreamed . . . that the oil industry would respond so enthusiastically to our introduction of the "Royal Scintillator." We were caught with our production down. We not only did not have enough instruments to supply the demand, we didn't even have enough catalogs. We apologize and wish to assure our customers that we are now in a position to give prompt service.

Not everyone agrees that the radiation survey technique is a proven method of oil field exploration. We agree that not enough data is available as yet, however, there is a growing body of opinion which holds that this is a valuable technique. Recent very encouraging results support this opinion.

We cannot guarantee that the Model 118 Royal Scintillator will locate oil, but we can guarantee that the Royal is the best instrument made for investigating the radiation pattern existing around oil fields. It is also the best instrument made for uranium prospecting, and its use for this purpose should not be overlooked by oil geologists.

Write now for our free pamphlet on "The Principles of Oil Field Detection with Scintillation Counters" and our complete catalog on Geiger Counters and Scintillation Counters.

PRECISION RADIATION INSTRUMENTS, INC.

2235 JT S. LA BREA AVE., LOS ANGELES 16, CALIFORNIA

Name_____ Title_____

Company_____

Address_____ City_____ State_____

PRECISION RADIATION INSTRUMENTS, INC.

World's Largest Manufacturers of Portable Radiation Instruments

BOOK REVIEW

Oil in the Soviet Union

By Heinrich Hassmann, Princeton University Press, 174 pp., $3.75

Translated by Alfred M. Leeston

Heinrich Hassmann's recent book *Oil in the Soviet Union* is an important contribution to the literature of the international petroleum industry.

Our knowledge of Russian oil has faded rapidly since the beginning of World War II. Although coordinated statistics were not available even then, many Westerners had the privilege of visiting the oil areas in the 1930's, and authentic publications describing the industry were currently available in the capitals of Europe. Since the war, however, these sources of information have dried up and assessments of the industry have been purely speculative.

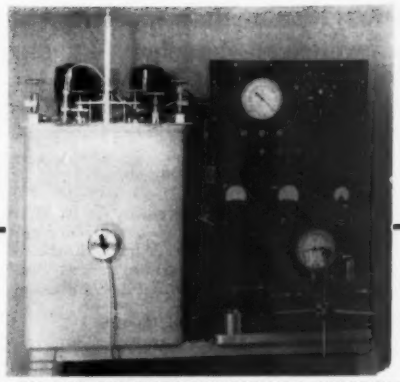
Hassmann has done a fine job of compiling and interpreting current knowledge of the Soviet industry. Particularly valuable are his descriptions of the new developments on the slopes of the Ural Mountains. Although the average analyst is inclined to consider that the heart of the Soviet producing and refining industry is in the general neighborhood of Baku, we now find that important segments of the industry are now widely distributed throughout the Soviet Union. The author's research, therefore, sheds some light on the vulnerability of the Soviet Union in time of war. With the bulk of production and refining located in the Caspian area, one could consider the industry highly vulnerable not only from the point of view of air attack on producing and refining installations, but also from the point of view that great transportation difficulties might be encountered in moving this oil to industrial areas and areas of potential military activity.

The gradual broadening of the base, as the industry moves into the heartland of the Soviet Union, provides a new measure of security.

In his analysis of the peace-time use of oil within the Soviet Union, Hassmann is not clear in explaining how this enormous nation can get along with relatively small quantities of petroleum fuels. He indicates that Russia has moulded its rates of production to fit the general economic pattern, but one always suspects — and Hassmann does nothing to dispell this suspicion — that the Russians are not yet capable of rapid development in this complex industry. Another question which Hassmann touches upon but does not satisfactorily answer is the question of oil supply for the eastern section of the Soviet Union where the only listed oil fields are those on the island of Sakhalin. This supply question becomes even more mysterious when one considers the probable extent of civilian requirements plus the relatively heavy demands for petroleum fuels caused by the Korean hostilities.

Hassmann is also inclined to offer apologies for the rather poor performance of the producing and refining industry in Russia under the supervision and management of the Socialistic State. These same apologies are also offered for the bad performance in Roumania. One suspects that Hassmann has simply used in his text the statements of the Russians themselves in this regard, because the hard facts reveal that both within the general Baku area and in Roumania, the Russians have inherited a ready-made industry in which the difficult pioneering and construction phases had already been completed under private ownership. Therefore, the well-worn and oft-repeated phrases of apology have a hollow ring.

A. H. CHAPMAN



NEW GAS SUPERCOMPRESSABILITY APPARATUS
Routine Test Instrument Exceeding
Research Laboratory Accuracy

INSTRUMENTS for the Oil Industry

Ruska Instrument Corporation specializes in the development and manufacture of scientific instruments for the oil and mining industries.

- Reservoir Engineering
- Pressure Measurement
- Volumetric Pumps
- Core Analysis

Ask for New CATALOG

Ruska Instrument Corporation

4607 MONTROSE BLVD. HOUSTON 6, TEXAS

more money in the bank . . .

YOU SAVE when you log as you drill with Geolograph because Geolograph gives the driller the information he needs to do the most efficient job! Shallow or deep . . . you get more for your drilling dollar with Geolograph on the job!

GEOLOGRAPH

MECHANICAL WELL LOGGING SERVICE

P.O. Box 1291 • Oklahoma City 1, Okla.

Farmington, New Mex. • Liberal, Kan. • Oklahoma City, Okla. • Bakersfield, Cal. Abilene, Houston, Odessa, Lubbock and Wichita Falls, Tex. • Shreveport, and Baton Rouge, La. • Casper, Wyo. • Glendive, Mont. • Sterling, Colo. Edmonton, Alberta, Canada

Pennsylvania State to Hold Annual Conference on Petroleum Production

Pennsylvania State University will hold its Eighteenth Technical Conference on Petroleum Production on Wednesday, Thursday, and Friday, October 6-8.

Afternoon Session, October 6

Some Factors Related to the Measurement of Electrical Properties of Porous Sandstones, by C. R. Holmes.
Progress in Electric Logging Research at Pennsylvania State University during 1953-54, by E. James Moore.
Definition of an Oil Sand by Quantitative Petrographic Analysis, by J. R. Emery and J. C. Griffiths.

Morning Session, October 7

Further Tests of Dimensional Orientation and Directional Permeability, by J. Hutta and J. C. Griffiths.
Recent Developments in Treating Water for Subsurface Injection, by T. M. Doscher and R. N. Tuttle.
A Correlation of Variables Affecting Oil Recovery by Surfactants in Water-Wet Porous Media, by J. G. Paez and John C. Calhoun.

Afternoon Session, October 7

The Inlet Saturation Distribution Transient in a Water Flood, by C. Stockwell and J. Warren.
Interrelationship Between Oil and Gas Relative Permeability, by A. T. Corey.
Use of Radioactive Iodine to Determine Saturation Distribution in a Five-Spot Model, by R. E. Wainerdi and R. F. Nielsen.

Morning Session, October 8

Increasing Brine Throughput Rates of Cores by Reduction of Oil Saturation, by R. M. McFarlane and R. B. Bossler.
A Study of the Three-Phase Equilibria for Carbon Dioxide-Hydrocarbon Mixtures, by A. H. Meldrum and R. F. Nielsen.

★★★

LELAB COUNTER TUBES ARE CUSTOM-BUILT!

Metal-Walled — Resist Shock

Lelab counter tubes are individually constructed, filled and tested to insure uniform stability and reproducible results. Except for a glass bead insulator, they are constructed entirely of metal.

The metal cylinder is used both as the envelope and cathode of the tube. This simplicity of design provides Lelab counter tubes with unusual strength and resistance to shock.

All Lelab component parts are confined within the diameter of the tube shell. This permits the close stacking of many tubes within a restricted area — an important advantage in radiation measurements.

Lelab counter tubes are available in a variety of production types; other designs can be obtained on special order.

Write us today, Dept. C., for complete information

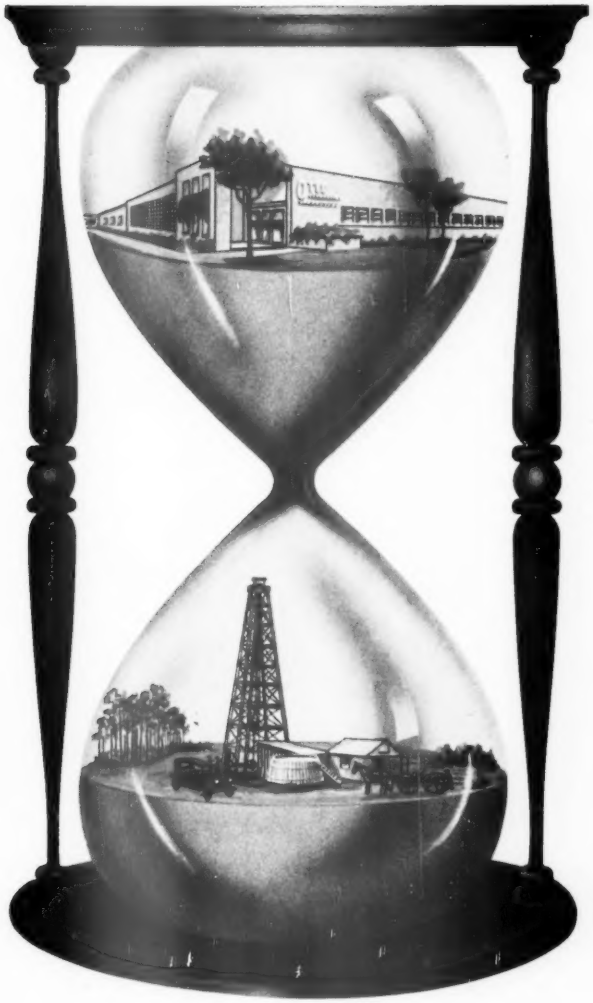
H. W. LEIGHTON LABORATORIES

26 Herman Street **Glen Ridge, N. J.**

ADVERTISERS' INDEX

Advance Oil Tool Co.	*
The Aldrich Pump Co.	23
Baash Ross Tool Co.	*
Baker Oil Tools, Inc.	4, 5
Baroid Sales Division	*
B & W, Inc.	138
Black, Sivalls & Bryson, Inc.	24
Byron Jackson Co.	*
Camco, Inc.	*
Cardinal Chemical, Inc.	*
Clark Bros. Co., Inc.	*
Cooper-Bessemer Corp.	*
Core Laboratories, Inc.	2
Dowell Incorporated	8
Dresser Industries	26, 27
Eastman Oil Well Survey Co.	103
Fluid Packed Pump Co.	*
Geolograph Co.	151
Guiberson Corporation	126
Geophysical Research Corp.	143
Grove Valve and Regulator Co.	22
Halliburton Oil Well Cementing Co.	134
Harbison-Fischer Mfg. Co.	*
Hughes Tool Co.	*
Hydril Co.	28
Johnston Testers	147
Kimray, Inc.	145
Kobe, Inc.	*
Lane-Wells, Inc.	Fourth Cover
Larkin Packer Co., Inc.	44, 45
H. W. Leighton Laboratories	152
Lufkin Foundry & Machine Co.	46
Magnet Cove Barium Corp.	*
McCullough Tool Co.	7
National Tank Co.	104
Oil Base, Inc.	*
Oil Center Tool Co.	*
Otis Pressure Control, Inc.	Third Cover
Perforating Guns Atlas Corp.	142
Precision Radiation Instruments, Inc.	150
Professional Services	144, 145
Rector Well Equipment	*
Ruska Instrument Corp.	151
Schlumberger Well Surveying Corp.	Second Cover
Security Engineering	25
Shaffer Tool Works	*
Sperry-Sun Well Surveying Co.	146
Visco Products Co., Inc.	21
Welex Jet Services, Inc.	6
The Western Company	20
Western Geophysical Co.	*

*In Previous Issues



OUR BEST 25 YEARS ARE AHEAD OF US....

OTIS PRESSURE CONTROL, INC.

Our Silver Anniversary

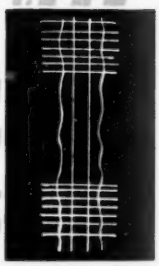
PROGRESS MADE THE OIL INDUSTRY and Otis WHAT IT IS TODAY

STILL THE ONLY SERVICE WHICH GIVES YOU

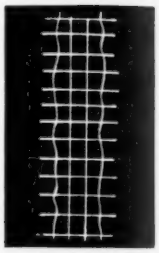
SEMI-SELECTIVE

Shaped Charge Perforating

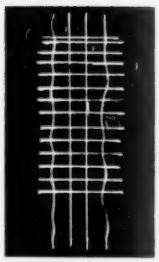
KONESHOT



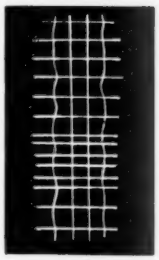
24 Shots in each of two separate 69" sections.



48 Shots in one 141" section.



48 Shots in one 69" section.



48 Shots with double shot density in a chosen section.

Lane-Wells' famous F-2 Semi-Selective Koneshot Gun is made to order for the many jobs which call for the deep penetration of Koneshot, but also need something more than the fixed pattern of regular shaped-charge perforating. Consisting of two 24-shot guns coupled in tandem, the F-2 Gun gives you — *on one run* — any of the options shown at the right. Available in 5 sizes, from 3⅛" o.d. to 5" o.d.

Write for further information

LANE-WELLS COMPANY

SEMI-SELECTIVE KONESHOT PERFORATING

Tomorrow's Tools - Today! ®

AK-706

General Offices, Export Office, Plant • 5610 So. Soto St., Los Angeles 58

LOS ANGELES • HOUSTON • OKLAHOMA CITY • LANE-WELLS CANADIAN CO. IN CANADA • PETRO-TECH SERVICE CO. IN VENEZUELA